SEIZE THE SYNERGY

A RESEARCH TO THE IMPLEMENTATION OF A COLLECTIVE SUSTAINABLE ENERGY SYSTEM FOR HEATING IN THE CITY-CENTER OF ARNHEM

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ABSTRACT

The Palace of Justice in Arnhem is an outdated building and in desperate need for renovation to meet the current energy standards. The Palace of Justice is an example of a building typology facing a renovation challenge, namely the traditional Dutch office buildings. For old energetically low-quality buildings, meeting the new-built standard is hard to realize with just a deep renovation. Solutions can be found in the way energy is used on an urban scale. This research focuses on the development of the concept of the cascading-machine, a collective heating system based on the principles of cascading and thermal energy storage. The simulation model developed for this research shows that by implementing a collective heating system in the city-center of Arnhem the energy consumption used for heating and cooling can be reduced with 62%. After optimization of the system, by means of increasing the efficiency, use of renewable heat sources and a building renovation strategy, the reduction of energy consumption used for heating and cooling can be as much as 89%. Despite the challenges regarding the technical and financial feasibility of a collective heating system, the research proves the working of the concept of the cascading-machine and shows the potential of innovative collective heating systems as an alternative for natural gas.

KEYWORDS *collective heating system, cascading-machine, heat grid, heat storage, heat exchange, heat cascading, optimization strategy, renewable energy*

1. INTRODUCTION

In 2015, the Paris Agreement stated that CO2 production should be reduced to nearly zero in the year 2050. The Netherlands are juridically obligated to meet these goals and are searching for solutions in different fields. One facet in the challenge for energy transitions is in the built environment, being responsible for 34% of the energy end-use (ECN, 2017). Within the built environment a renovation challenge is arising for the traditional Dutch office buildings. The traditional Dutch office buildings are built between 1965 and 1985 and in desperate need for a deep renovation to meet the current climate standards. One of those buildings is the Palace of Justice in Arnhem. For old energetically low-quality buildings, meeting the new-built standard is hard to realize with just a deep renovation, for that reason this building typology can be a problem in the energy transition. The aim of this thesis is to find an innovative and multi-applicable way for the energy transition for the typology of the traditional Dutch office building, using the Palace of Justice and its surrounding buildings as a showcase.

In the Netherlands, heat grids are seen as one of the most important alternatives for natural gas, which results in a demand for innovative systems (Boeters, 2019). A theoretical concept of an innovative form of collective heating is presented in REAP2, by ir. Wisse, in forms of the cascading-machine (Van den Dobbelsteen et al., 2011). A cascading-machine is a concept of a sustainable collective energy system for heating based upon the principles of heat cascading and thermal energy storage. Heat cascading is the reuse of waste heat from one building as a supply for the other building as is shown in figure 1. An additional part of the cascade-machine is the thermal energy storage at different temperature levels, which enables energy exchange and interseasonal energy storage. The cascading-machine is a low-energetic system which uses all potential out of the energy consumed and thereby reduce the losses to a minimum.

The objective of this research is the development of the theoretical concept of the cascading-machine into a proposal for a sustainable collective energy system implemented in the city-center of Arnhem. In order to test and improve the operation of the system, a simulation model is created. Initially, the system is imbalanced and therefore an optimization strategy for the system needs to be developed. Therefore, the research question is: *What strategy can be developed to optimize a sustainable collective energy system for heating based on the principle of heat cascading and thermal energy storage, for a cluster of building in Arnhem including the Palace of Justice*? To answer this question four sub-questions are formulated: *how does a collective energy system work?; how can it be implemented in the city-center of Arnhem?; what are the optimization potentials?; what optimization strategy can be developed?* The sub-questions are respectively answered in the four chapters. Finally, conclusions are drawn and recommendations are formulated.

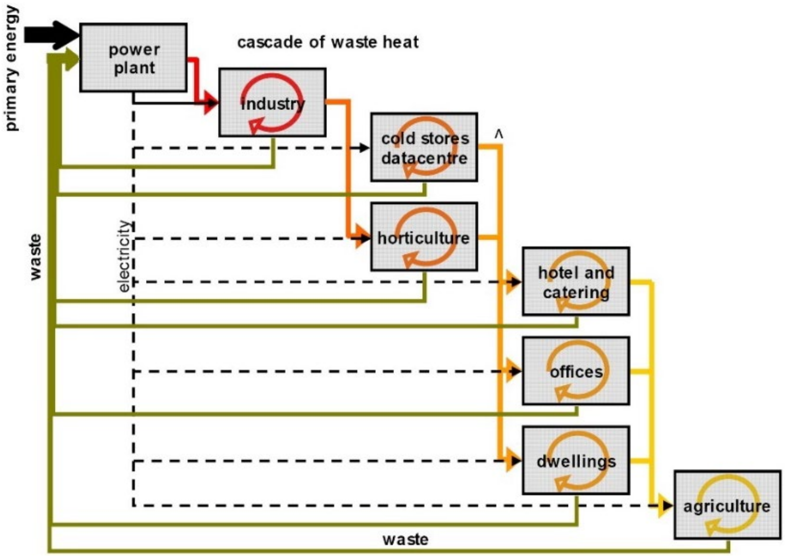


Figure 1: Energy flows of a cascaded energy system. Retrieved from: *Energy potential mapping* (p.5) by Broersma, Fremouw & Van Den Dobbelsteen, 2013.

2. WORKING PRINCIPLE

2.1. Intro

The concept of the cascading-machine is based on the principle of heat cascading and interseasonal heat storage on multiple temperature levels. The differentiation of temperature levels is based on the temperatures required for heating a building: none-insulated buildings are heated on high temperatures, poorly insulated buildings are heated on mid-temperatures, and well-insulated buildings can be heated on (ultra) low temperatures. This chapter discusses the working principle of the cascading-machine that is presented by ir. Wisse in the research project 'REAP2' (Van den Dobbelsteen et al., 2011). For the development of the theoretical concept guidelines are retrieved from the EU-research project 'City-zen' (Van den Dobbelsteen et al., 2019).

The concept of the cascading-machine is illustrated in simplified form in figure 2. The figure shows the steps of the heat carrier water throughout the system. As indicated in purple at the bottom right of the figure, the waste incineration plant provides 80°C to the buildings heated on high temperatures (HT). By heating the building, the high temperature reduces to 60°C. This waste heat is used to heat the buildings that are heated on mid-temperature levels (MT), shown in red in the figure. If the supply is larger than the demand, the heat can be stored in mid-temperature thermal energy storage (MT-TES) and be used when needed. By heating the MT-buildings the temperature decreases to 40°C and can be used to heat the buildings heated on low temperatures (LT) or be stored in the low-temperature thermal energy storage (LT-TES), as indicated in yellow. By heating the LT-buildings the water decreases to 20°C and can be used for heating the buildings heated on ultra-low temperatures or be stored in the ultra-low-temperature thermal energy storage (ULT-TES). This final step is shown in green. In the heating process of the ULT-buildings, the water decreases to the original groundwater temperature of 10°C and is returned.

The concept consists of multiple principles and in order to understand the technical operation of the cascading-machine these principles are elaborated individually. At first, the general operation of heat-grids is discussed, then thermal energy storage is further explained. Subsequently, the possibilities of heat exchange are discussed and finally, the concept of cascading is elaborated.

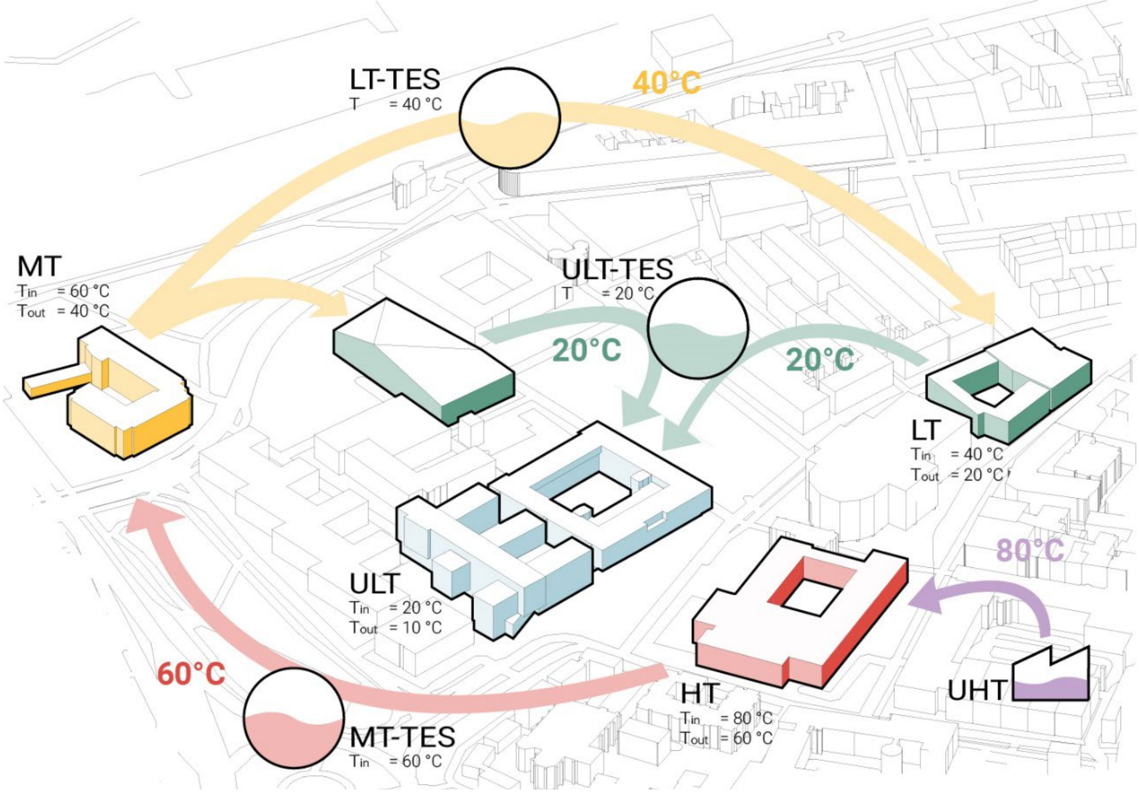


Figure 2: Conceptual thermal energy flows cascading-machine in city-center Arnhem. Own image, 2020.

2.2. Heat grid

Heat grids are underground networks that distribute heated water to the buildings. Heat sources used to supply heat to the water are for example industrial waste-heat, geothermal heat, solar heat and residual heat from the process of cooling. The temperature of the heat grid can be divided into four different temperature levels, namely the high-temperature heat grid (HT), the mid-temperature heat grid (MT), the low-temperature heat grid (LT) and the ultra-low temperature heat grid (ULT). In this paragraph, the properties, the advantages and the disadvantages of each heat category are discussed respectively. The temperature boundaries of the categories vary in the literature. In this paper the temperature values set by City-zen are used (Van den Dobbelsteen et al., 2019).

2.2.1. HT-heat grid

The HT-heat grid is the most common type of heat grid in the Netherlands. An HT-heat grid supplies heat from 65 °C up to 130 °C. These high temperatures can be reached by burning fossil fuels in heavy industry, burning of biomass, or burning waste in incineration plants. Another less commonly used high-temperature heat source is deep-geothermal energy. The main advantage of the HT-heat grid is that all types of building can be connected to the heat grid without any mayor adaptations to the existing buildings. The heat from the network can be used directly for heating and tap water by using a heat exchanger. The disadvantage of HT-heat grid is that it has significant transport losses due to the high temperatures. At present, Arnhem has an HT-heat grid where heat is provided by a waste incineration plant. The temperature of the existing heat grid is 120 °C and the return heat is 40 °C. The incineration plant has a heat buffer resulting in a constant supply of heat to the heat network (Lambregts, n.d.).

2.2.2. MT-heat grid

The temperature of MT-heat grid is between 40°C and 65°C. Heat sources for this heat grid can be solar-collectors or geothermal-heat or the return-heat of an HT-heat grid. The mid-temperature heat net is suited for reasonably insulated buildings, with energy label D and better (CE Delft, 2019; Van den Dobbelsteen et al., 2019).

2.2.3. (U)LT-heat grid

The temperature of an LT-heat grid is below 40°C. Heat sources for LT-heat grids can be shallow geothermal heat, residual heat in the cooling process of light industry such as residual heat of the cooling process in e.g. supermarkets, ice-rinks and datacenters or the return-heat of an MT-heat grid (CE Delft, 2019). The LT-heat grid is suited for well-insulated buildings with an energy label B and better. The buildings connected should have a low-temperature heating system, such as floor heating, wall heating and low-temperature on vectors or radiators. A booster heat-pump is required to heat the tap-water up to 55°C to meet the legislations for domestic water (CE Delft, 2019).

If the temperature of a heat grid is below 25°C and direct space heating is not possible, we speak of an ULT-heat grid. An ULT-heat grid can be used as a pre-heated medium for heat pumps in well-insulated buildings. Low- and ultra-low temperature heat distribution involves little heat losses and allows many potential heat sources to be connected, such as residual heat from the cooling process.

2.3. Thermal energy storage

Interseasonal thermal energy storage exists in several forms, but large scale energy storage can be done in two ways, namely aquifer thermal energy system (ATES) and borehole thermal energy system (BTES) (Mangold & Deschaintre, 2015). The vision plan for Arnhem proves that both methods of thermal storage on a larger scale are suitable for the city-center of Arnhem (Gemeente Arnhem, 2012).

An ATES is an open system, based on direct heating of groundwater and storage in aquifers. Since the system is in direct contact with the groundwater, soil surveys and observations are necessary to maintain the quality of the subsurface. The system is less sensitive to a change in supply and demand, as the amount of water in the aquifer can differ over time (Drijver, Van Aarssen, & De Zwart, 2012). A BTES is a closed system and therefore requires an equilibrium. According to Mangold & Deschaintre, BTES are profitable from a volume of 20,000 m³ (2015). Despite it is a closed system, it can easily be expanded as total demand changes when for example another building is connected to the system.

In the Netherlands, the maximum temperature of underground thermal heat storage is 25°C, which is not sufficient for the envisaged system (Drijver, Van Aarssen, & De Zwart, 2012). Deviation from the maximum temperatures is only permitted in pilot studies, where the temperatures can reach up to 80°C. The legislation says that the total amount of groundwater pumped up must be returned to the ground, resulting in an unchanged groundwater level. Besides, the total extraction and provision of heat to the subsurface must be levelled out in a period of five years.

2.3.1.HT-TES

High-temperature thermal energy storage can be used to store a heat-transferring medium to a maximum of 80°C. The main disadvantage of an HT-TES is the recovery efficiency, since HT-TES comparatively large heat losses and therefore is not commonly used. The recovery efficiency of an HT-TES is between 40 and 70% (Drijver et al., 2012). Hence, HT-TES is a suitable way to store residual heat from the industry if the heat source is not continuously available.

2.3.2.MT-TES

Due to the legislation about the maximum temperature for thermal energy storage in the Netherland, the thermal energy storage between 40°C and 65°C is an unconventional temperature for thermal energy storage. The recovery efficiency of MT-TES is between 60 and 80%.

2.3.3.(U)LT-TES

Low-temperature heat storage is the most commonly used temperature for heat storage in the Netherlands. The commonly used heat-/cold storage systems in the Netherlands (WKO) are based on the LT-TES. The developments of these LT-TES in the last decades and the use of low-temperatures result in high recovery efficiency. The recovery efficiency of the LT-TES is at a minimum of 70% and can be as high as 90% (Drijver et al., 2012). The ULT-TES is based on even lower temperature and therefore is assumed that the recovery efficiency 80 and 90%.

2.4. (Interseasonal) heat exchange

Part of the cascading machine is the heat-exchange between different building functions. Different buildings have a different demand for heat and cold throughout the year. An essential condition for heat exchange in a neighbourhood is the difference in building functions. By heat exchange between these different building functions, thermal energy that is normally lost can be stored and reused. The peak moments of heat and cooling demand possibly vary throughout the year. To bridge this interseasonal variance, thermal energy storage can be used. Certain functions have a significant heat demand or production and can be used to create a balance in a system. This optimization potential is called an energetic-implant and is elaborated in chapter 4.

2.5. Heat cascading

As the name implies, heat-cascading is the most important principle of the cascading-machine, hence extensively discussed. In short, heat cascading is the reuse of waste heat from one building as a supply for the other building as is shown in figure 1 and 2. Heat cascading is based on the categorization of buildings by the temperature demand of the building. A division is made based on the aforementioned, high temperature (HT), mid-temperature (MT), low-temperature (LT) and ultra-low-temperature (ULT). The waste heat of a building can be used as the supply heat of the subsequent buildings. By doing so, all potential out of the energy consumed is used and thereby reduce the losses to a minimum. Thermal energy is the energy flow where most of the energy is lost in the built environment. Van den Dobbelsteen et al. stated in 2009 that heat cascading is effective rather than efficient since it is 600% more sustainable than the existing heating system.

3. METHODOLOGY: HEAT FLOW MODELLING

3.1. Intro

The aim of this research is to implement a collective sustainable energy system for heating in the city-center of Arnhem. In order to test and improve the operation of the system, a heat flow model is created. The heat flow model consists of three steps as can be seen in figure 3. At first, the current thermal energy consumption is mapped, functioning as input data for the model. Subsequently, the theoretical concept of the cascading-machine, as presented in chapter two, is modelled in order to test and show the technical operation of the system. Hereafter, the output of the model is examined and reviewed with the aim of improving the system. The steps are respectively elaborated in the coming three paragraphs. The development of the optimization strategy is discussed in the next chapters.

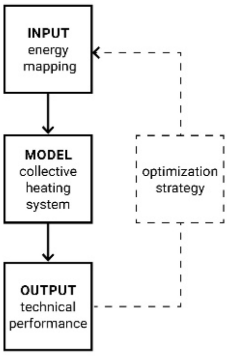


Figure 3: Schematic heat flow modelling steps. Own image, 2020.

3.2. Input - Energy mapping

3.2.1. Intro

In order to analyze the operation of the system, it is essential to identify the current thermal energy consumption as accurately as possible. Despite the quantity of energy data available online, the data is often not usable as it is expressed on the larger scale and based on national averages. Based on three steps, a more accurate estimation of the energy consumption of the buildings in the cluster has been made. The steps are shown in figure 4 and can be used to make a realistic estimation of the energy consumption and heating and cooling demands of most of the buildings in the Netherlands. Each of the steps is elaborated in this paragraph respectively.

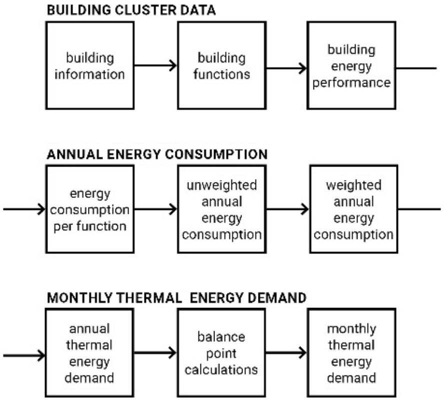


Figure 4: Schematic energy mapping steps. Own image, 2020.

3.2.2. Building data

The used building cluster consists out of 27 buildings and building blocks in the area around the market in the city-center of Arnhem. An overview of the buildings in the cluster can be found in appendix 1. The buildings in the cluster consist out of 6 different building functions, which are office, cinema, school, healthcare, hotels, historical buildings, restaurants and housing. The functions are, where possible, further specified in function types. Of all the buildings in the cluster, data is gathered regarding the addresses, building years, gross floor area and the building functions (Kadaster, n.d.). The energy label of the buildings is, where possible, based on the online geodata (PDOK, n.d.). The missing energy labels are based on the method used by the ECN, wherein they defined the energy label based on the building decree that applied at the time of the construction of the building (Arnoldussen, Van Zwet, Koning, & Menkveld, 2016).

Then the buildings are categorized by the heating temperatures the buildings are heated on, as described before. This subdivision into heating temperatures indicates the potential heating temperature of a building, rather than the actual heating temperature. Buildings with an energy label of E and worse are assumed to be HT-heated. Buildings with an energy label D and C are assumed to be MT-heated. Buildings with an energy label B and A are suited for LT-heating. Lastly, buildings with an A+ label and better are potential heat on ULT.

3.2.3. Annual Energy Consumption

The annual gas- and electricity consumption for residential buildings is retrieved from PDOK. This data is based on the data of Liander, the local grid operator. The energy consumption is based on the actual annual energy consumption of the residential buildings within the postal code of the city-center in Arnhem. For the residential buildings the energy consumption is expressed in the average total annual gas- and electricity use per unit of housing types in the Arnhem city-center. For the calculation of the current energy consumption of the non-residential buildings within the building cluster, key-figures are determined based on several studies (Sipma & Rietker, 2016; Meijer & Verweij, 2009; Rijkswaterstaat, n.d.). For non-residential buildings the energy consumption key-figures are based on the annual gas- and electricity use per square meter gross floor surface.

By multiplying the number of residential buildings with the energy consumption per unit, the annual energy consumption per residential building is determined. By multiplying the gross-floor area with the average energy consumption per square meter, the total energy consumption of the non-residential buildings is determined. In total, this comes down to unweighted annual energy consumption of 24 GWh natural gas and 8.1 GWh electricity.

The energy consumption of the building types is based on yearly averages of various buildings in the Netherlands. To determine even more realistic energy consumption of the buildings within the building clusters the individual energy performance of the buildings is included in the model in forms of energy label-weighting factors. For office buildings is the effect of the building-scale on energy consumption are included by means of building-scale weighting factors. After including the weighting factors in the model, the total energy consumption of the building cluster amounts 27.3 GWh natural gas and 7.6 GWh electricity, which can be found in appendix 2.

3.2.4. Monthly thermal energy demand

In order to calculate the monthly heat demand, the annual energy consumption is divided into the energy consumption categories, such as heating, lighting, cooling etcetera. In literature, these divisions are expressed in percentages of the total energy consumption and therefore the gas-consumption and electricity consumption are added up (Meijer & Verweij, 2009; Van Timmeren, 2012). For all functions, a literature-based assumption has been made for a division in the following categories: space-heating, water-heating, space cooling, product cooling, appliances, catering, lighting, IT and remaining. The assumed energy division per building type can be seen in appendix 3. Since the collective energy system is focused on thermal energy the categories space heating, water heating, space cooling and product cooling are used. The total annual energy consumption for space heating amounts15 GWh; for water heating 1.6 GWh; for space cooling 9 GWh; for product cooling 1 GWh. It can be assumed that heating is mainly done with natural gas and cooling with electricity, but this distinction is no longer be made in the model.

Now the annual energy consumption for heating and cooling is determined, the actual annual energy demand for heating and cooling can be calculated. The difference between the energy consumption and the energy demand is the efficiency of the heating and cooling source. Assumed is that buildings built before 2017 are heated by use of a gas boiler with a coefficient of performance, COP, of 1. For buildings built onwards 2017, is assumed that heating is done by use of an electric boiler or heat pump with a COP of 3. For water heating a COP of 1 assumed. For cooling is assumed that space cooling is done by means of air-conditioning with a COP of 4. Finally, product cooling is assumed to be done with a refrigerator with a COP of 5. After multiplying the annual energy consumption with the efficiency of the heating- and cooling device the total anal thermal energy demand for space heating is 19 GWh; water heating remains 1.6 GWh; space cooling is 7,2 GWh, product cooling is 0,5 GWh.

In the process of cooling heat is produced. For active cooling, the produced heat equals the cooling-demand summed up with the electrical consumption of the cooling device. For passive cooling-the heat, production equals to the cooling-demand. In the model is assumed that in the cooling process water is used as a cooling medium. The temperature increase is expressed in an upgrade from temperature categories. For active cooling is assumed that cold water is heated to MT. For passive cooling process a temperature increases from cold to ULT.

Finally, the actual annual heat demand and supply is converted into monthly data by use of the hourly weather data. Since the total annual heating demand is known, a simplified version of balance-point calculations is used and explained in detail in appendix 4. Figure 5 shows the total monthly thermal energy demand and supply per heating-category per month. The shown data is used as input for the cascading machine.

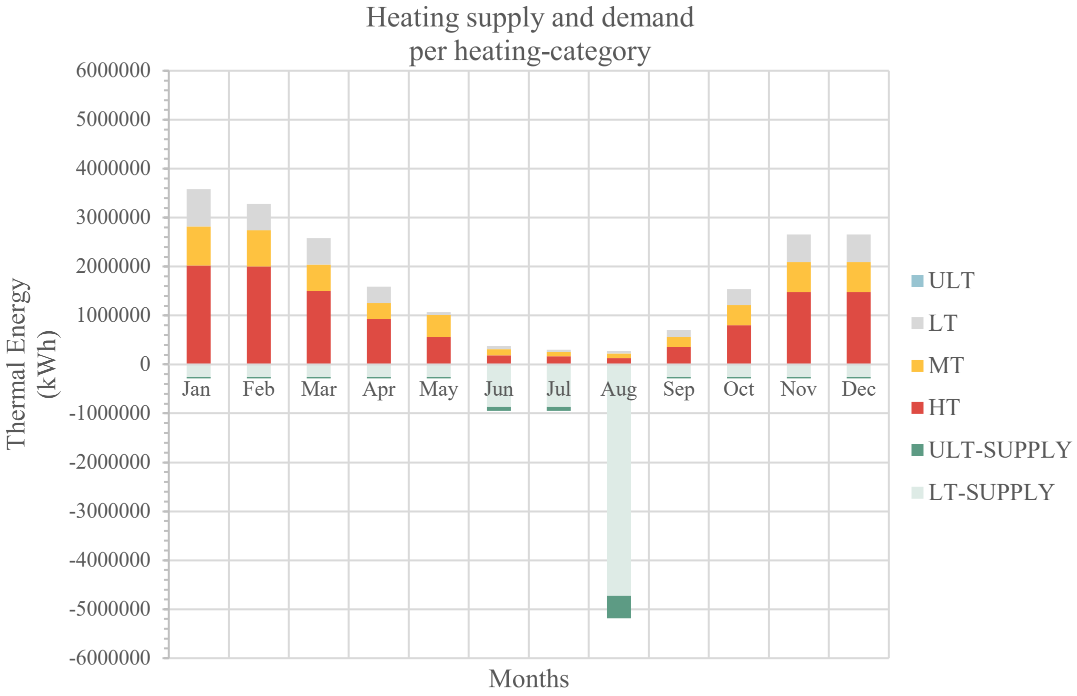


Figure 5: Monthly thermal energy demand and supply per heating temperatures. Own image, 2020.

3.3. Collective heating system

The envisaged collective energy system for heating is based on a combination of the cascade machine as presented in REAP (Van den Dobbelsteen et al., 2009) and the collective sustainable energy system for heating as outlined in City-zen (Van den Dobbelsteen et al., 2019). A deviation in the planned system compared to the before-mentioned systems is that there is no high-temperature thermal energy storage since the AVR waste incineration plant, which produces the heat for the heat grid in Arnhem, already has a heat buffer and therefore can provide a constant supply of HT-heat to the heat grid. Based on the combination of the principles of heat cascading, thermal energy storage and various heating options a simulation model is developed. A representation of the components and the operation of the system can be seen in figure 6.

Initially, the thermal energy demand and supply is expressed in unit of power. In order to gain a better understanding of the system the thermal energy flow is expressed in volumes of heated water, using the thermal heat capacity of water. By doings so the temperature conversions within the system can be included, the capacity of the system can be determined and the energy used for pumping can be defined.

The heat flow within the system can be seen in figure 6. The water temperature entering the system, supplied by the heat exchanger, is determined at 100°C and can be cascaded and lowered down until the original groundwater temperature of 10°C. The cascading is done respectively by the following steps: 100°C water loses 15% of its temperature during transport to the HT-building; the water arrives at the HT-buildings at 85°C; the water required for HT-heating corresponds to the specific energy dissipation of water decreasing from 85 to 65°C. The water is then reused as a supply for the MT-buildings or is stored in the MT-TES and later used. At these temperatures, a transport loss of 20% is estimated. Likewise, the MT-buildings delivers to the LT-building or LT-TES. The temperature supply is 40°C and the efficiency of storage and transport is estimated at 90%. The residual heat from the LT-buildings then goes to the ULT-Buildings or ULT-TES. The supply temperature is 20°C and the efficiency 95%. In the buildings, the water is boosted by a heat pump and the cold that is released in this process will supply back to the original cold groundwater of 10°C.

In addition to cascading, boosting the temperature is an important part of the model. At this moment heating of water is done in two ways. First is by means of the residual heat from the cooling process. Cooling takes place in two ways, namely active and passive cooling. Active cooling is cooling by use of a cooling device such as a heat pump or air-condition. The term passive cooling is used for cooling based on the transport of cold water throughout a building, for example by use of floor-cooling. For active cooling is assumed that cold water is heated to MT, so from 10 to 40°C. For passive cooling process a temperature increases from cold to ULT, from 10 to 20°C. Another way for boosting the temperature is by means of heat pumps. These heat pumps provide heat when the process of cascading is not sufficient to meet de demand. These heat pumps are therefore called back-up heat pumps and can heat water from C>ULT, ULT>LT and LT>MT. In order to upgrade the water from MT>HT, a heat exchanger is connected to the local heat grid, fed by the AVR waste incineration plant. This is because heat pumps, boosting water from 60°C to 80°C (MT>HT) are not yet efficient and will result in high electricity consumptions. In time, the provision of heat by means of the heat grid will be replaced with a renewable heat source.

The above-mentioned steps occur in the system in a certain order. The first step is determining the heat produced as residual heat from the cooling processes. Next, the heat is cascaded throughout the system respectively form HT, MT, LT and in the end the ULT-heating. A cascading-step consists of three steps. First, if available residual water from the previous heat-category is used for heating. If not available water from the TES is used for heating. If both are not available, water from colder heating categories is boosted and used for heating. HT-heating differs from the other categories due to the absence of an HT-TES. Heating the HT-buildings is done by boosting water from the MT-TES, by use of the local heat network.

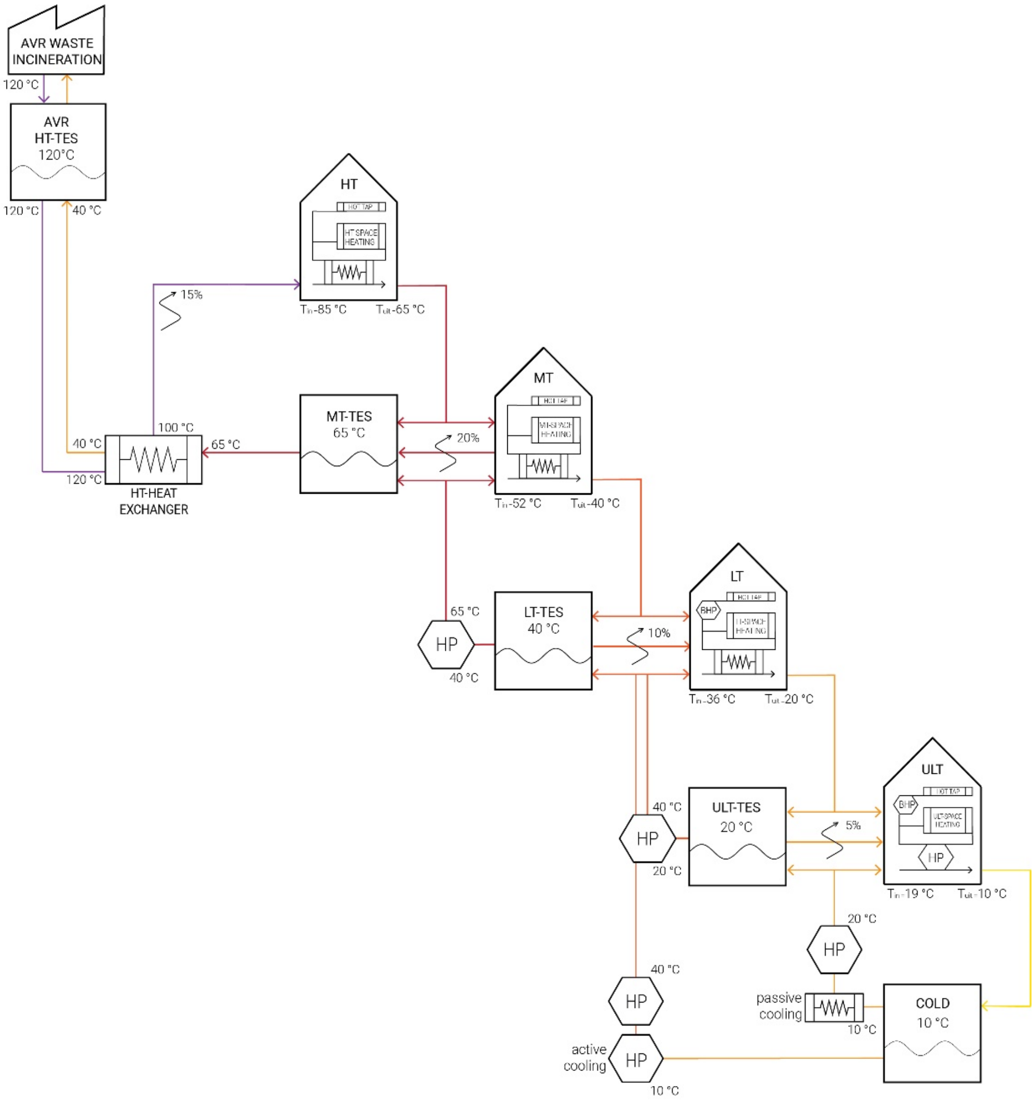


Figure 6: Flow diagram collective heating system. Own image, 2020.

3.4. Output – Results

The operation and performance of the system can be measured by means of three requirements First, the total volume water subtracted and provided to the subsurface should be balanced in a period over five years. Next, the total volume of water heated by the heat grid and back-up heat pumps should be reduced to nearly zero. Lastly, the total energy consumption used for heating, cooling and pumping should be less than the original consumption used for heating and cooling. These three requirements are elaborated on subsequently.

The balance of the volume of water per thermal energy storage can be seen in figure 7. The graph shows total volume per month as a sum of the supplied water and the retrieved water from the TES, or in other words, the graph shows the total water retrieved from the C-TES and the distribution over the ULT, LT and MT-TES throughout the year. The water subtracted and provided to the subsurface should be balanced. It can be seen that the system is not in balance since at the end of the year there is residual water in the LT-TES and ULT-TES. This can be explained due to the absence of buildings heated on ULT-temperatures, which would return water to the C-TES as a result of the heating process by means of heat-pumps. Another thing that can be seen is the large increase in volume of water in the LT-TES in Augustus. This can be explained by residual heat as a result of the active-cooling process.

Figure 8 shows the volume of water that is needed to be boosted in temperature, to meet the heating demand on the various temperature levels. Heating water from MT>HT is done by means of the heat-grid, in the other cases heat is provided by the use of the back-up heat pumps. Ideally, water is only boosted form MT>HT, while the rest provided by the principle of cascading and the residual heat from the cooling process. The peak at the beginning of the year can be explained by the fact that there is no heated water in the system and the total demand for HT-heating should be boosted throughout the system. Furthermore, the graph shows that throughout the year constantly water should be heated from LT>MT and MT>HT. This can be explained by the majority of high- and mid-temperature heated buildings and the absence of renewable ways to provide mid- and high temperatures.

The total amount of energy needed for heating, active cooling and pumping water is shown in figure 9. For heating using a heat-pump (ULT>MT and LT>MT) and active cooling (C>LT) an COP of 6 is used. To include the environmental impact of the process of waste incineration for providing heat to the heat-grid, the energy consumption is assumed to be a sixth of the heat subtracted from the heat-grid (MT>HT). In conclusion, the total electrical energy used in the system for pumping is 0.3 GWh. The amount of energy used for heating and cooling is 7 GWh. This is a total of 7.3 GWh which is used for providing 28.6 GWh of thermal energy, which results in a COP of 6.1. Despite the fact there is residual waste in the system, the proposed model only uses 39% of the original annual energy consumption of the building cluster. When the usage of waste heat from the incineration plant is considered as completely renewable, the system would have a COP of 10.3 and uses only 21% of the original annual energy consumption.

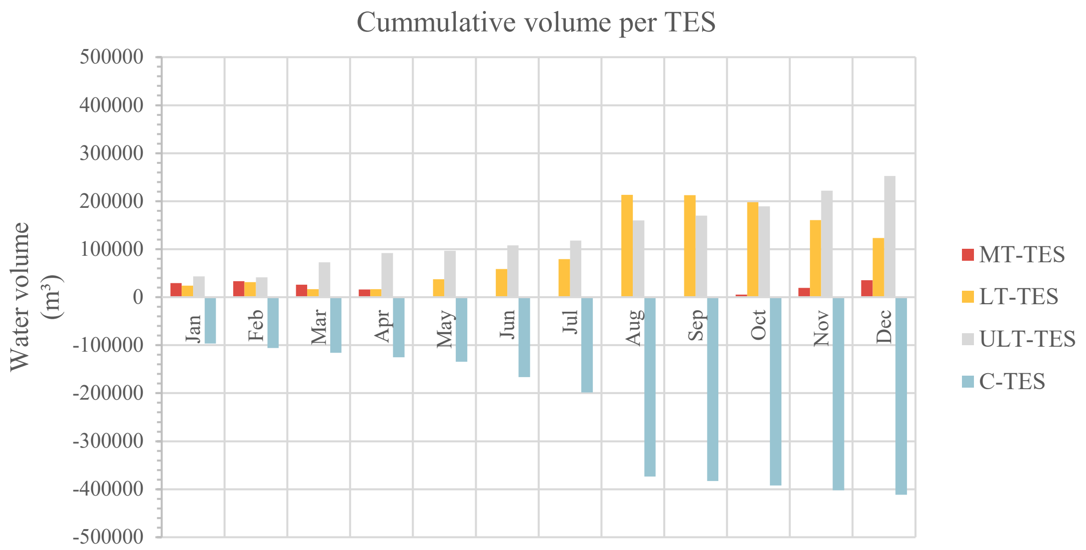


Figure 7: Cumulative volume per TES (2025). Own image, 2019.

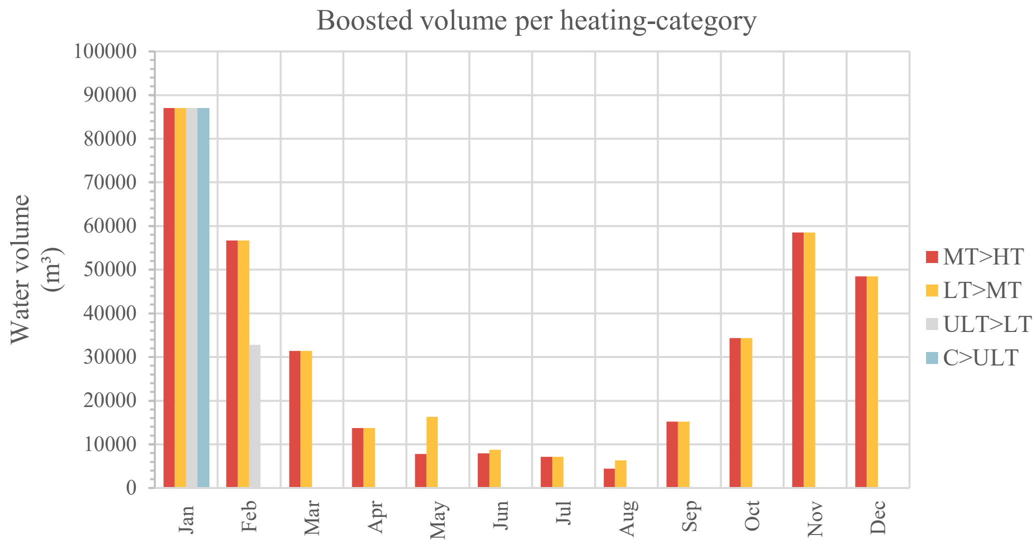


Figure 8: Volume water boosted in temperature (2025). Own image, 2019.

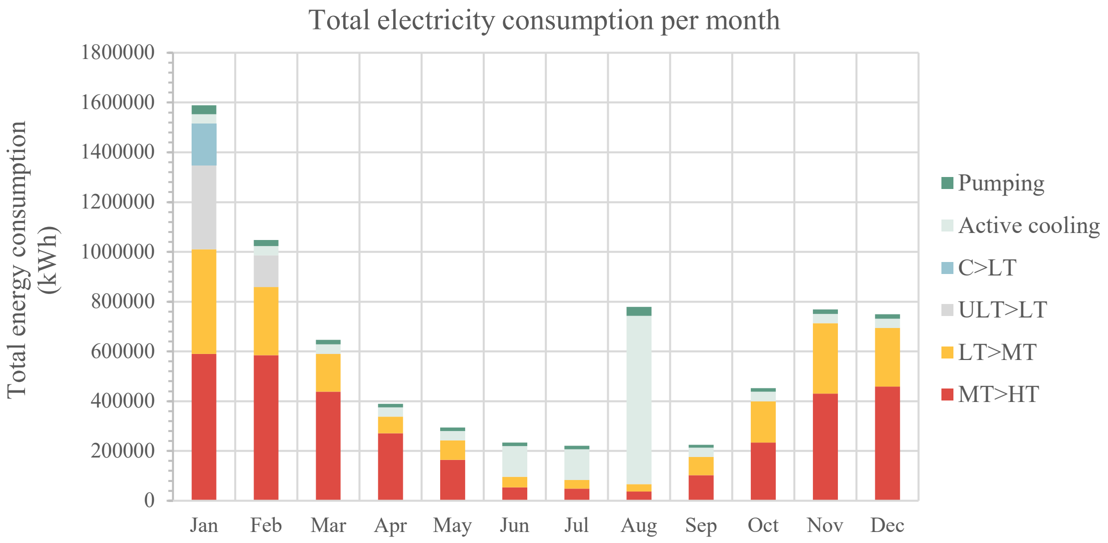


Figure 9: Annual energy consumption (2025). Own image, 2019.

4. OPTIMIZATION POTENTIALS

4.1. Intro

The optimization potentials of the collective heating are mapped. They are based on the optimization steps proposed at Ramplaankwartier, a similar concept of a collective heating system in Haarlem as lectured by Jansen (2019). The optimization consists of three steps: reducing the demand, increasing the efficiency of the system and the production of renewable energy. This chapter studies how the optimization steps can be applied in Arnhem. By doing so the optimization potentials are identified that can be used as a part of the optimization strategy of the collective heating system.

4.2. Reducing demand

Reducing the total demand can be done by improving the energy performances of the buildings connected to the system. Improving the energy performance of a building affects the heat and cold demand, the heat demand of the buildings will decrease, while the cold demand will increase. An additional possibility with regard to upgrading the building energy performances is that it can be done in a way that enhances the balance of the system.

Jansen (2019), makes a distinction between three levels of improvement, namely BAU (business as usual); 'towards low-temperature heating' and NZEB-renovation. The BAU improvement level consists out of the minimal improvement measures such as cavity wall insulation, double glazing and floor- and roof insulation. Assumed is that a BAU-improvement can improve a building from an HT heated building into an MT heated building. The 'towards low-temperature heating'-improvement includes improvements as high-quality insulation, triple glazing, low-temperature radiators and CO2 driven mechanical exhaust ventilation. Assumed is that this improvement can improve an MT heated building into an LT heated building. Finally, the NZEB renovation includes improvement as new roofs, added building skin, floor heating and ventilation with heat recovery. Assumed is that an NZEB-renovation can improve a building from an LT heated building to an ULT heated building.

4.3. Increasing the efficiency

The proposed cascade system is a very efficient system, as it consumes only 38% of the original energy consumption. However, the system does not meet the requirement that it is in balance, so there is still room for improvement. A way to further increase the efficiency of the system itself is to optimize the temperature limits used in the system. Normally, to achieve the most efficient way of heating a building the aim is to achieve the greatest possible heat release of the heating devices, meaning the temperature difference between the supply and the return of a heating device should be as large as possible. Deviating from this may increase the cascading effect of the system, in order to find optimum, complex calculations must be done and therefore the temperature limits will remain constant in this research.

Another way to create a balance in the system is by use of energetic implants. In REAP, this is described as an intriguing term for adding a function to the missing links in the energy supply chain. (Van den Dobbelsteen et al., 2009). Energetic implants are building functions with high heat- or cold demand, such as supermarkets, datacenters, ice rinks, swimming pools and saunas. An energetic implant can have such an influence on the total thermal balance of a collective heating system that it can be strategically implemented to overcome shortages or surpluses. Various energetic implants are studied and discussed in appendix 5. It can be concluded that most energetic implants have a demand for high temperatures or supply of low-temperatures. Neither of these is demanded in the model. However, in further versions of the system energetic implants can be of added value.

4.4. Renewable energy production

The final step in improving the system is the use of renewable energy. Since the system is based on heating, renewable thermal energy sources are studied and elaborated in appendix 6. The studied renewable energy sources are solar, geothermal and biomass. In doing so, the electric potential of solar energy is also studied. From this, it can be concluded that the electrical energy potential of solar energy in the plan area is more than sufficient to meet the demand. The calculation of solar heat is complex due to the varying temperatures and will be at the expense of electricity production by the PV panels. Another constant and unlimited heat source is geothermal for MT-heating and deep geothermal for HT-heating. Biomass appears to be unprofitable on the proposed scale in an urban context.

5. OPTIMIZATION STRATEGY

5.1. Intro

As described in the previous chapter, various optimization forms can be implemented in the currents system. To implement such a strategy a division is made in four different steps, namely the concept development, technical and financial concept feasibility, the user preferences and the implementation plan (Jansen, 2019). The proposed strategy focuses on the local-specific concept development over a period of 30 years, whereby the technical operation is tested by the simulation model. The original energy consumption and energy performances of the building cluster in 2020 are used as a starting point and benchmark. The first step is 2025, wherein the first version of the collective energy system for heating is implanted. This first version is optimized by use of the previously investigated optimization potentials. For this reason, a distinction has been made between reducing the energy demand of the system, improving the efficiency of the system and the production of renewable energy. The first optimization steps are implemented in 2030, focusing on reducing energy demand. The second optimization steps are implemented in 2040, aiming for a balanced system.

5.2. Reducing demand

The optimization 2030 focuses on reducing the thermal demand of the system resulting in several building energy performance optimization measures. In 2030, the renovations as obliged by the government are carried out current legislation states that by 2023 all office buildings must have at least energy label C and by 2030 an energy label A (Arnoldussen et al., 2016). Besides, the government stated that future deep-renovation project for office buildings aims for an energetic improvement to label A+ or better (Knops, 2019). Next to the obliged renovations, the buildings with the most urgent need for renovation are renovated. The most urgent buildings are the HT-heated buildings, i.e. buildings with a label E and worse. The HT-heated building is improved by means of the BAU-improvement and therewith become an MT-heated building, corresponding to a building with label D or better. The optimization steps in 2040, consist of improvement of the energy performances of the remaining buildings. For MT-heated buildings, this is done by use of the 'towards low-temperature-buildings'-improvements, and therewith become an LT-heated building corresponding to an energy label A in the model. The LT-buildings are improved using NZEB-improvement and therewith become an ULT-heated building corresponding to an energy label A++ in the model. The effect of the improvement of the energy performances of the buildings leads to a shift in energy-labels and therewith the heating temperatures. Figures 10 and 11 show the thermal energy consumption per energy label and heating temperatures as a percentage of the total energy consumption.

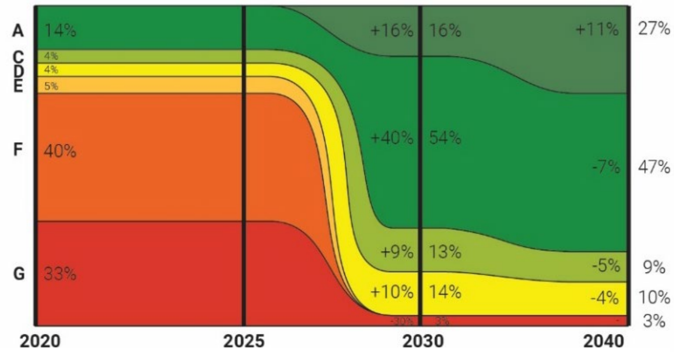


Figure 10: Energy demand per energy label. Own image, 2019

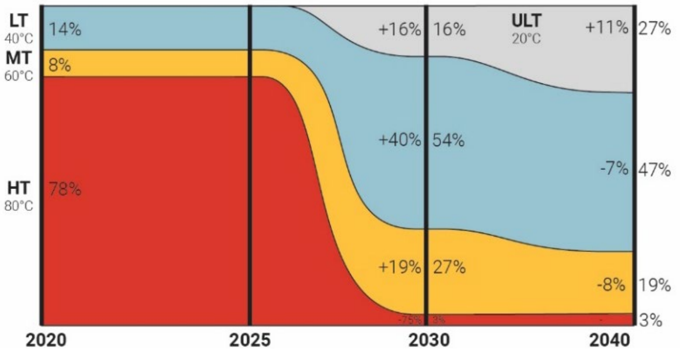


Figure 11: Energy demand reduction per heating temperature. Own image,

5.3. Increasing the efficiency

By studying the overall balance in the system (figure 5,7,8 and 9), it appears that in the current situation there is no cold production and therefore no water that can be returned to the original groundwater aquifer. This leads to an unused residual heat stored in the ULT-TES. In the model, the way to produce cold water is by the residual cold of the process of heating by means of a heat pump. After the renovation, the share of buildings heated on LT increases resulting in an even greater imbalance. By improving the Palace of Justice into an A++ building, the temperatures needed for heating changes from HT to ULT and therewith cold water can be returned to the original aquifer.

5.4. Renewable energy production

The last step is the improvement of the thermal energy sources used for heating. Figure 12 shows the developments of the heat sources per heating temperature expressed in percentages of the total thermal energy demand per heating temperature as a result of the improvement of the thermal energy source. This paragraph elaborates on the development of the thermal energy source of each heating temperature over time.

In 2020 natural gas is used for high-temperature heating. By implementing the system gas will be replaced with a connection to the local heat grid. As the demands for HT-heating decreases due to the renovations, the connection to the heat grid can be replaced by heat pumps, heating water from mid- to high temperatures. The warmest heating temperature benefits the least from cascading.

In 2020, the heat source for MT-heated building is gas. In 2025, the MT-heat demand is largely provided by cascading. However, the renovations result in a significant reduction of HT-heated buildings, which makes MT-heated buildings the warmest heating temperature. This results in a shift of heat source from cascading to other heat sources. MT-heat can be provided by heat pumps, but preferably is done by use of the local heat-grid. To replace the non-renewable heat-grid by a completely renewable heat source, geothermal energy is used as thermal heat source in 2040.

In 2020, the heat source for LT-heated buildings is gas. By the implementation of the cascading-machine, the residual waste from the active cooling process and cascading MT-heat provides heats to the LT-heated buildings. The renovations in 2030 and 2040 lead to an increase in the amount of LT-heated buildings, resulting in back-up heat pumps compensate for the shortages.

Initially, no buildings are heated on ULT. The renovations of 2030 lead to a small demand to ULT-heating, which completely can be supplied by the passive cooling process. More buildings will be heated on ULT in 2040, resulting in that residual heat of the active cooling process will no longer be sufficient. Partly this can be cascaded from the LT-heated buildings and partly this must be boosted by use of a heat pump.

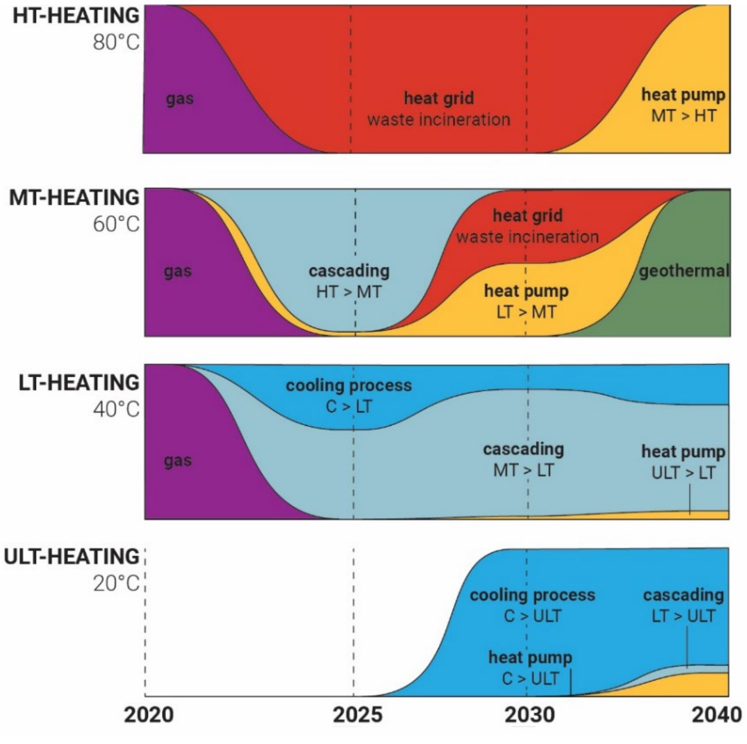


Figure 12: Thermal energy source per heat-category. Own image, 2019

5.5. Results

The total energy consumption used for heating the buildings in the building cluster is originally 19 GWh. This is used to provide a thermal heating and cooling demand of 28 GWh, which result in a total COP of 1.5. The total effect of the improvement strategy can be seen in figure 13, wherein 2020 is set as the starting point and benchmark.

By implementing the collective heating system the total thermal energy demand remains the same since no adjustments were made to the building energy performance. The implementation of the system results in a total energy consumption of 7 GWh, used for heating, cooling and pumping water, equal to a COP of 6.1. By implementing the system an energy reduction of 62% is realized and thereby gas is no longer used as a thermal heat source.

The building optimization planned for 2030, result in a total thermal demand of 25 GWh. This increase in thermal demand compared to previous years can be explained by the improvement of the building performances: the increase of cooling demand has a larger impact than the reduction of the heating demand. However, for providing this 25 GWh of thermal energy, 5 GWh of electrical energy is used for heating, cooling and pumping water. This results in a COP of 6.8 and an energy reduction of 75% as compared to the original energy consumption.

Lastly, after the second renovations, the total thermal energy demand of the building in the system is 24 GWh. The transition to the use of geothermal energy results in energy consumption for heating, cooling and pumping of 2 GWh. This equals to COP of 12 and an energy reduction of 89% compared to the original energy consumption of the building cluster. With the use of PV-panels, all the required energy can be generated renewable and transform the building-cluster into a zero-energy cluster.

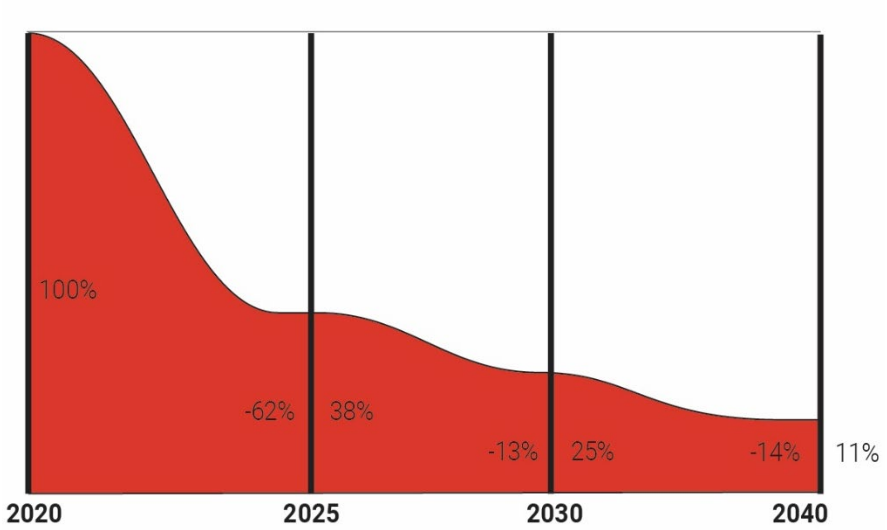


Figure 13: Total energy consumption building cluster. Own image, 2019

6. CONCLUSION & RECOMMENDATIONS

The Palace of Justice in Arnhem is an outdated building and in desperate need for renovation to meet the current energy performances and therefore this building typology can be a problem in the energy transition. This research focused on the development of the theoretical concept of the cascading-machine into a proposal and optimization strategy for a sustainable collective energy system for heating implemented in the city-center of Arnhem.

The simulation model showed that the implementation of the system results in an energy reduction of 62%. By implementing the system, the challenge for the energy transition from gas to other heat sources is completed since gas is replaced using waste heat from an incineration plant, cascading, residual heat of the cooling process and electrical heat pumps. Optimizing the system, by reducing the thermal energy demand, improving the efficiency and the transition to renewable energy sources, can result in a reduction of the total energy consumption up to 89% compared to the original energy consumption of the building cluster. The remaining energy demand of 2 GWh yearly can locally be produced by PV-panels and therewith transform building cluster in a zero-energy cluster.

This first study of the energy performance of this type of collective heating system has shown that the concept can be profitable in the city-center of Arnhem. The impact and scale of the intervention were not considered in the study. In reality, large-scale interventions will have to be made on building-scale and building-cluster scales, such as the construction of the pipelines, the drilling of soil for the TES and the connection of the individual buildings using heat exchangers. Further research into the technical and financial feasibility must show whether it is actually possible to implement the system. In addition, research will have to be carried out into the user performances and, based on this, an implementation plan must be elaborated.

Despite the challenges for the technical- and financial feasibility of a collective heating system, this research showed that innovative collective heating can be the answer for the energy transition on a larger scale. In my opinion, further research and more pilot studies should be realized as soon as possible, since in the meantime time passes, deadlines for the Paris Agreement draw near and the urgency for the energy transition is increasing.

7. REFERENCES

Arnoldussen, J., Van Zwet, R., Koning, M., & Menkveld, M. (2016). *Verplicht energielabel voor kantoren*. Retrieved from http://www.eib.nl/pdf/verplicht_energielabel_voor_ kantoren.pdf

Boeters, B. (2019). Warmtenetten in tien jaar drie keer zo groot. *Technisch Weekblad*. Retrieved from https://www.technischweekblad.nl/artikelen/tech-achtergrond/warmtenetten-in-tien-jaar-drie-keer-zo-groot

CE Delft. (2019). *Factsheet LT-warmtenet*. 5. Retrieved from https://www.ecofys.com/files/files/collectieve-warmte-naar-lage-temperatuur.pdf

Drijver, B., Van Aarssen, M., & De Zwart, B. (2012). High-temperature aquifer thermal energy storage (HT-ATES): sustainable and multi-usable. *Innostock 2012 - 12th International Conference on Energy Storage*, (January), 1–10.

Gemeente Arnhem. (2012). *Structuurvisie Arnhem 2020 l doorkijk 2040*.

Jansen, S. (2019). *Urban Energy Transition Challenges [Powerpoint]*. Retrieved from https://brightspace.tudelft.nl/d2l/home/192548

Kadaster. (n.d.). Basisregistratie Adressen en Gebouwen. Retrieved November 1, 2019, from https://bagviewer.kadaster.nl/lvbag/bag-viewer

Knops, R. (2019). *Routekaart stelsel Kantoren*.

Lambregts, G. (n.d.). Warmtenet Arnhem. Retrieved November 20, 2019, from https://www.energiekaart.net/initiatieven/warmtenet-arnhem/

Mangold, D., & Deschaintre, L. (2015). *Large Systems Seasonal thermal energy storage*. 1–48. Retrieved from www.solites.de

Meijer, P. H., & Verweij, R. (2009). *Energieverbruik per functie voor SenterNovem*.

PDOK. (n.d.). PDOK Viewer. Retrieved November 1, 2019, from https://www.pdok.nl/viewer/#

Sipma, M. D. A., & Rietkerk, J. M. (2016). *Ontwikkeling energiekentallen utiliteitsgebouwen: Een analyse van 24 gebouwtypen in de dienstensector en 12 industriële sectoren*. https://doi.org/ECN-E--15-068

Van den Dobbelsteen, A., Broersma, S., Blom, T., Fremouw, M., Sturkenboom, J., Keeffe, G., … Vandevyvere, H. (2019). *City-zen - roadmap Amsterdam - D4.6 V1.5_181103*.

Van den Dobbelsteen, A., Tillie, N., Doepel, D., De Jager, W., Joubert, M., & Mayenburg, D. (2009). *REAP Rotterdam energy approach and planning: towards CO2 neutral urban development*. Retrieved from https://www.researchgate.net/publication/328232605

Van den Dobbelsteen, A., Tillie, N., Fremouw, M., Wisse, K., Doepel, D., Genten, L., … Daamen, T. (2011). *Reap2 Rotterdamse Energie Aanpak & Planning*.

van Timmeren, A. (2012). Climate integrated design and closing cycles. In *Sustainable Urban Environments: An Ecosystem Approach* (pp. 313–339). https://doi.org/10.1007/978-94-007-1294-2_12

8. APPENDIX

8.1. Building data

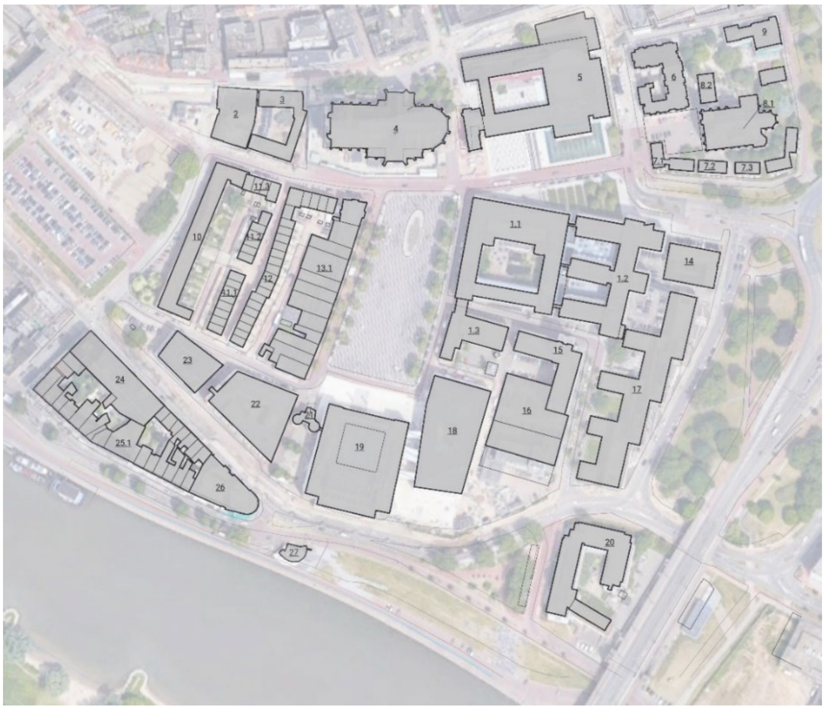
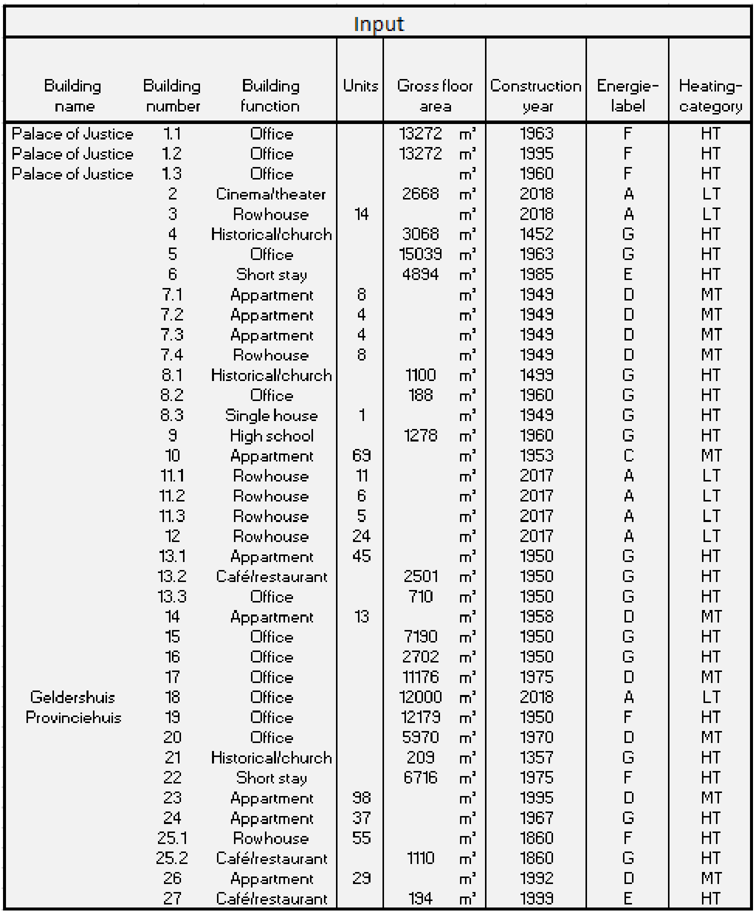


Figure 1: Buildings part of the building cluster. Own image, 2019.



Input							
Building name	Building number	Building function	Units	Gross floor area	Construction year	Energie-label	Heating-category
Palace of Justice	1.1	Office		13272 m²	1963	F	HT
Palace of Justice	1.2	Office		13272 m²	1995	F	HT
Palace of Justice	1.3	Office		m²	1960	F	HT
	2	Cinema/theater		2668 m²	2018	A	LT
	3	Rowhouse	14	m²	2018	A	LT
	4	Historical/church		3068 m²	1452	G	HT
	5	Office		15039 m²	1963	G	HT
	6	Short stay		4894 m²	1985	E	HT
	7.1	Appartment	8	m²	1949	D	MT
	7.2	Appartment	4	m²	1949	D	MT
	7.3	Appartment	4	m²	1949	D	MT
	7.4	Rowhouse	8	m²	1949	D	MT
	8.1	Historical/church		1100 m²	1499	G	HT
	8.2	Office		188 m²	1960	G	HT
	8.3	Single house	1	m²	1949	G	HT
	9	High school		1278 m²	1960	G	HT
	10	Appartment	69	m²	1953	C	MT
	11.1	Rowhouse	11	m²	2017	A	LT
	11.2	Rowhouse	6	m²	2017	A	LT
	11.3	Rowhouse	5	m²	2017	A	LT
	12	Rowhouse	24	m²	2017	A	LT
	13.1	Appartment	45	m²	1950	G	HT
	13.2	Café/restaurant		2501 m²	1950	G	HT
	13.3	Office		710 m²	1950	G	HT
	14	Appartment	13	m²	1958	D	MT
	15	Office		7190 m²	1950	G	HT
	16	Office		2702 m²	1950	G	HT
	17	Office		11176 m²	1975	D	MT
Geldershuis	18	Office		12000 m²	2018	A	LT
Provinciehuis	19	Office		12179 m²	1950	F	HT
	20	Office		5970 m²	1970	D	MT
	21	Historical/church		209 m²	1357	G	HT
	22	Short stay		6716 m²	1975	F	HT
	23	Appartment	98	m²	1995	D	MT
	24	Appartment	37	m²	1967	G	HT
	25.1	Rowhouse	55	m²	1860	F	HT
	25.2	Café/restaurant		1110 m²	1860	G	HT
	26	Appartment	29	m²	1992	D	MT
	27	Café/restaurant		194 m²	1999	E	HT

Figure 2: Building data. Own image, 2019.

8.2. Energy weighting factors

Since the energy consumption of the building types is based on yearly averages of all the buildings in the Netherlands, Weighting factors must be taken into account to determine realistic energy consumption. The gas- and electricity consumption of the building types are corrected by two factors, namely the energy label of the building and the impact of the building scale. The impact of the energy label on the energy consumption of the building is based on the Energy Performance Efficient and therefore a simplified percentages are used. (Sipma & Rietkerk, 2016).

As shown in figure 1, the gas-consumption of buildings with lower energy performances is significantly higher. This is due to the higher amount of heat losses due to the lack of insulation. The electricity consumption of buildings with higher energy performances is significantly higher. An explanation for this can be the presence of modern applications, such as electric boilers, mechanical ventilation and cooking.

Figure 2 shows the impact of the scale of an office related to the gas- and electricity consumption of the building. As shown, the gas consumption of the building decreases as the scale of the building increases. This can be explained by the increase of efficiency of the application for space heating and the ratio between façade and building-volume. In comparison to the gas-consumption, electricity consumption increases as the building-scale increases. This is due to the increase of people working in the offices and their use of applications and electronic devices.

Figure 3 shows the unweighted annual energy consumption of all the building in the building cluster. Figure 4 shows the effect of the weighting factors and therewith a more realistic annual energy consumption of the buildings in the building cluster.

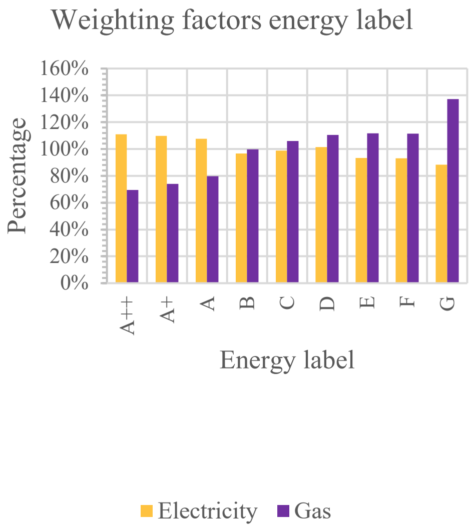


Figure 1: weighting factors building energy performance. Own image, 2019

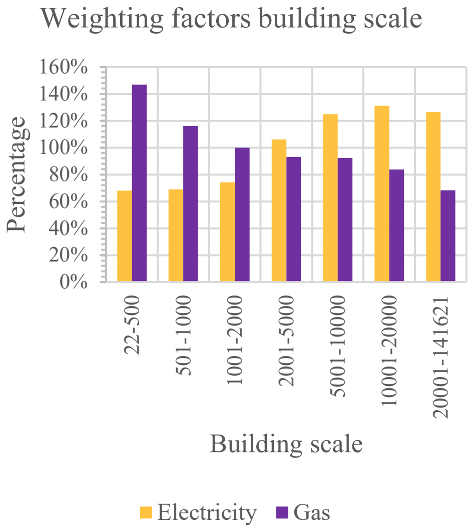


Figure 2: weighting factors building scale. Own image, 2019

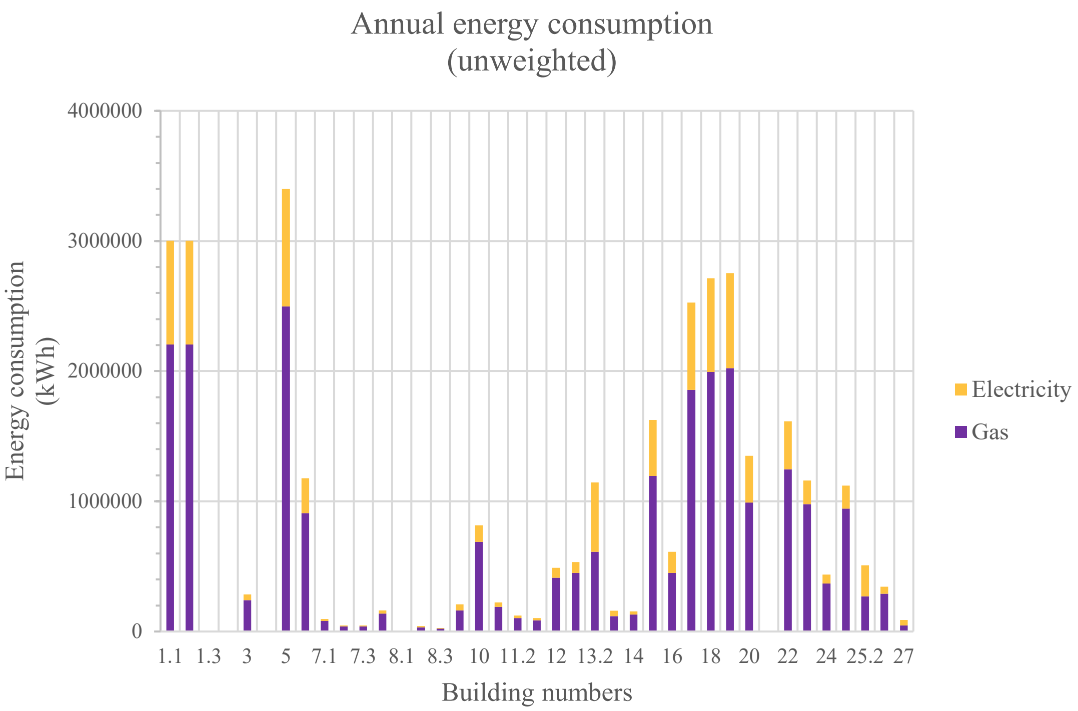


Figure 3: Unweighted annual energy consumption per building. Own image, 2019.

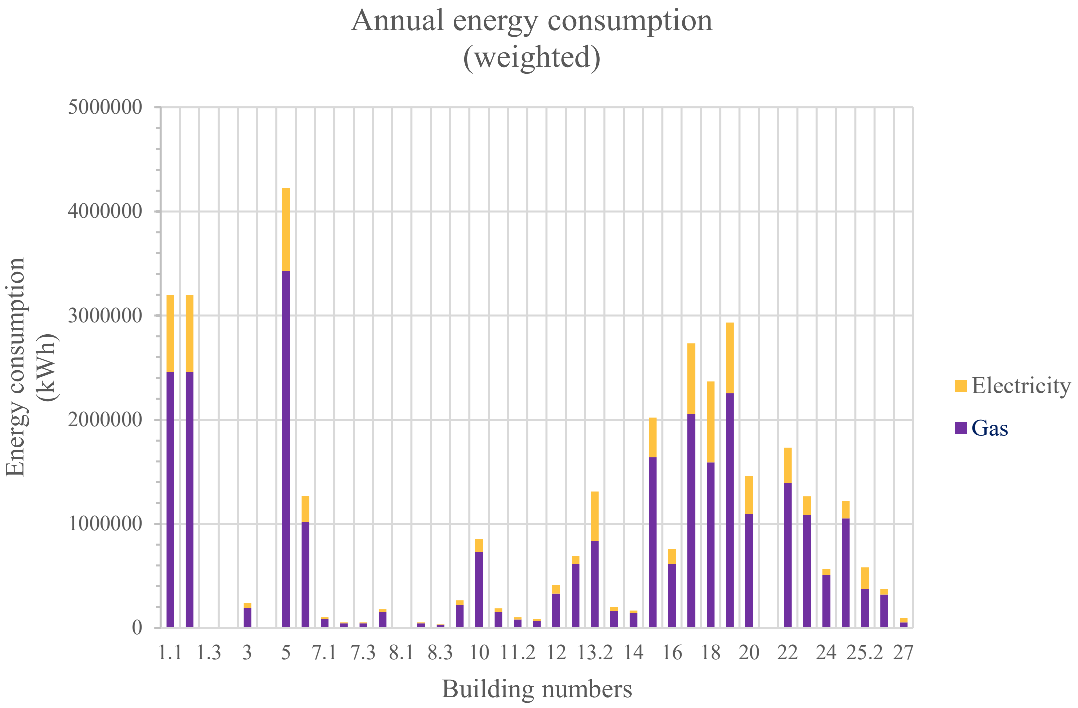


Figure 4: Weighted annual energy consumption per building. Own image, 2019.

8.3. Energy division per building function

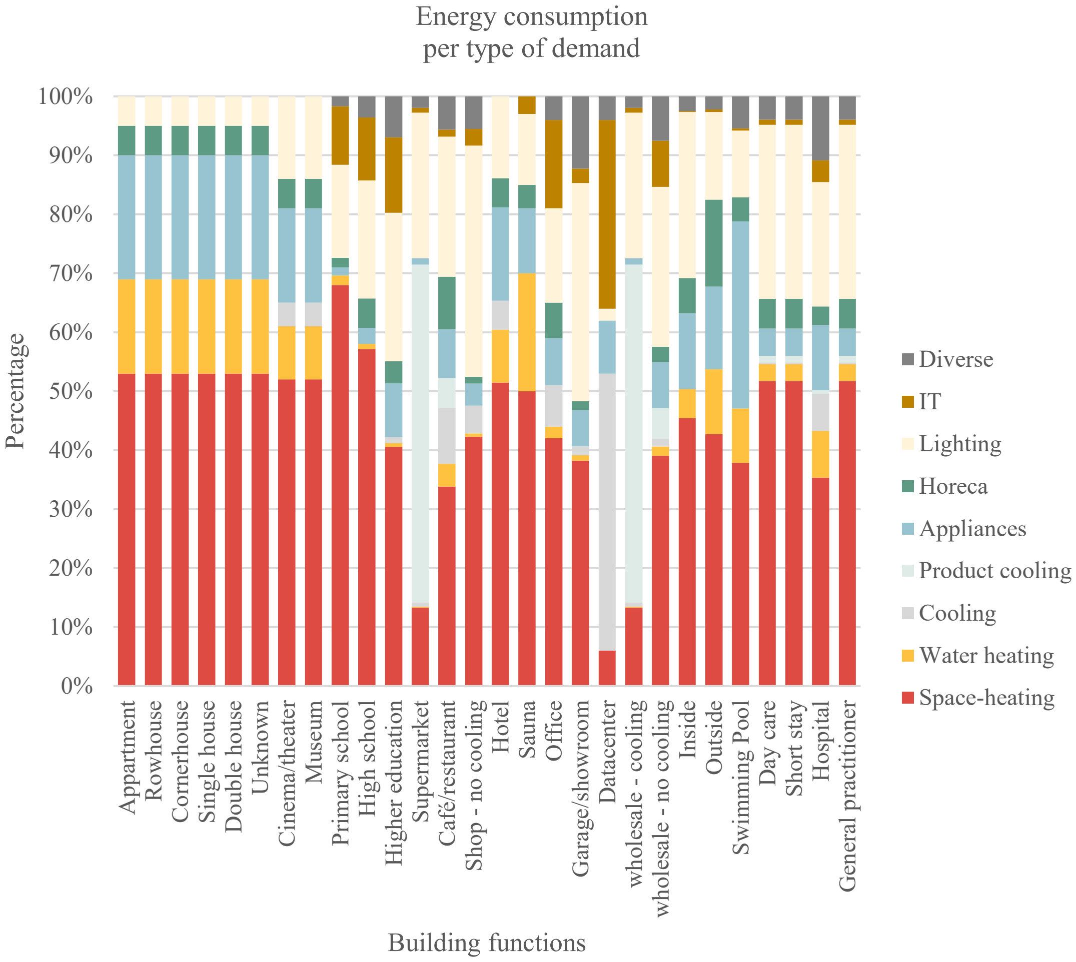


Figure 1: Energy division per building function. Own image, 2019.

8.4. Monthly thermal energy weather calculations

The actual heating- and cooling demand of the buildings are based on several weather parameters, the internal heat load, heat loss due to ventilation, transmission and infiltration. For the calculation of the energy demands of the building a simplified method used, since the annual end-use for heating and cooling is already known. To create an insight in this data the hourly data is converted to the monthly heating and cooling demands. To estimate this heating- and cooling balance point is determined for the residential and non-residential buildings. The heating balance point is when the outside air temperature is below the desired inside temperature. Vice versa, the cooling balance point is the point where the outside air temperature is above the temperature that a building needs cooling.

The balance point is influenced by several factors as the occupancy of the building, internal heat load and heat losses. To do so some rough estimations are made. Assumed is that the presence of people in a building creates an internal heat load between 2°C till 4°C; the desired temperature of a building in winter is 20°C and in summer 24°C. When nobody is in the building the building should not exceed a minimum temperature of 15°C. From this information the following parameters are set: a building needs heating when people are presences in the building and the outside temperature is below 16°C; a building needs cooling when people are present in the building and the outside temperature is above 20°C. Assumed is that residential buildings don't have cooling. The total distribution over the year can be seen in figure 1.

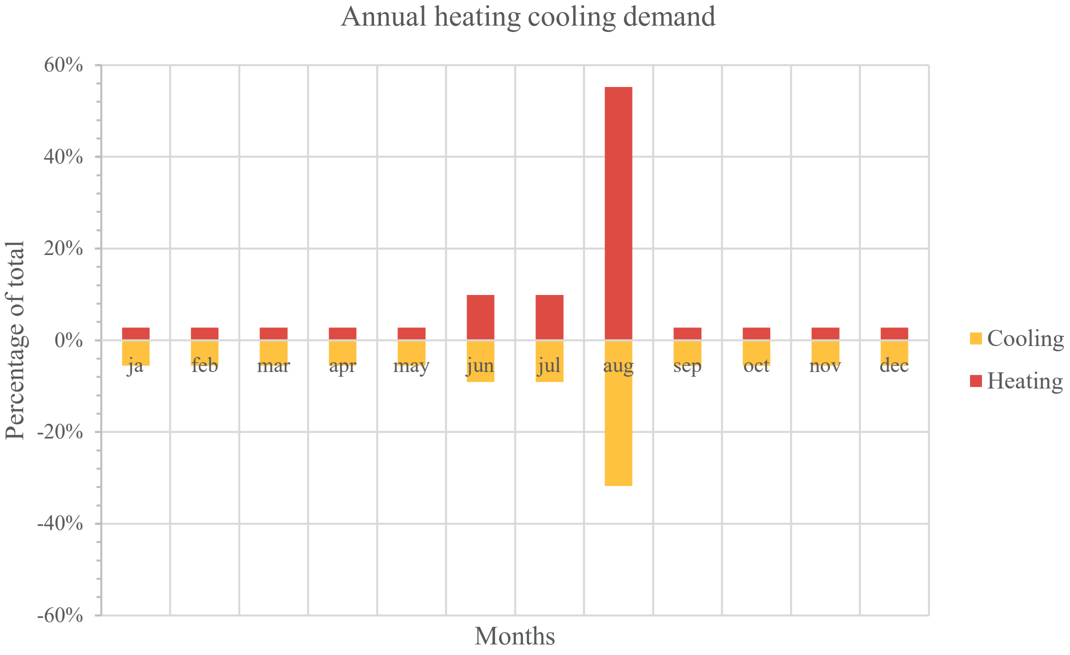


Figure 1: Heating and cooling demand over the year. Own image, 2019

8.5. Energetic implants

A way to balance the system is to add an ergetic implant. In REAP, this is described as an intriguing term for adding a function to the missing links in the energy supply chain. (Van den Dobbelsteen et al., 2009). Energetic implants are functions with high heat demand or cold demand. Buildings with a cold demand have a heat supply due to the heating of the cooling water. It is assumed that the heat production for active cooling, by means of a heat pump, refrigerator or air conditioning does not exceed 40°C and thus falls into the LT category. Building functions with excessive heat production in this heat category are for instance a supermarket or wholesale, data center and a skating rink. There are also buildings with excessive heat demand and therefore can function as energetic implants. Functions with an excessive heat demand are for example a swimming pool or a sauna. For the calculations below, key figures from the literature have been used (Meijer & Verweij, 2009; Sipma & Rietkerk, 2016).

8.5.1. Supermarket

In a supermarket, 57% of the total energy consumption is used for product cooling. A supermarket uses 449 kWh per square meter per year. On average, 257 kWh/m² is used to cool products. It is assumed that a in a supermarket a refrigerator has an average COP of 5, which corresponds to a heat production of 1,285 kWh per square meter.

8.5.2. Datacenter

On the one hand, a data center uses 32% of its total energy for servers and electronics. This is converted into heat on a one-to-one basis, which is equivalent to a heat production of 688 kWh/m² per year. On the other hand, 47% of the total energy consumption is used to cool the server rooms. It is assumed that a data center cools with a COP of 3, which equates to a total heat production of 3030 kWh/m².

8.5.3. Ice rink

For the energy consumption of a skating rink, a small-scale temporary outdoor skating rink in Delft was used as an example. The skating rink's energy consumption for ice cooling is 110,000 kWh per skating season. A skating season last 2 months. It is assumed that this skating rink cools with a COP of 1 and with that produces 110.000 kWh of heat in the winter period.

8.5.4. Swimming pool

A swimming pool annually uses only 9% of its total energy for heating the water and 38% of its energy for space heating. The total energy consumption of a swimming pool amounts 234 kWh/m². It is assumed that the heating of the water is effective and has a COP of 5, for the space heating a COP of 1 is assumed. This results in a total heat demand of 196 kWh/m².

8.5.5. Sauna

A sauna consumes a total of 309 kWh/m² per year, of which it uses 50% for space heating and 20% for heating. It is assumed that the heating of rooms with a COP of 2 and the heating of water with a COP of 1. This result in a total heat demand of 371 kWh/m².

8.6. Renewable heat potentials

8.6.1. Solar

The total area of the site is approximately 170,000 m². The total roof surface of the buildings on the site is 53,000 m². It is assumed that 60% of this roof area can be used for solar energy, either in the form of photovoltaic panels or solar collectors.

According to PVGIS, an independent photovoltaic geographical information system, the yield of a solar panel with a peak capacity of 250 Wp is 230 kWh per year in Arnhem (PVGIS, 2012). This amounts to 182 kWh per square meter per year. The potential photovoltaic energy in the total area is approximately 40 GWh. The maximum amount of electrical energy that can be captured on the roofs of buildings is 7.3 GWh. The total amount of electric energy required for pumping water and heating domestic water is 4.3 GWh. The total available roof area is, therefore, more than sufficient for the generation of the necessary electric energy.

To capture heat from the solar energy, there are two types of solar collectors, the flat plate solar collector and the vacuum tube solar collector. It is assumed that the annual heat output of these panels is respectively 450 kWh and 500 kWh. The total amount of heat that can be captured by means of solar collectors on roofs is 14 GWh for the flat plate solar collector and 16 GWh for the vacuum tube solar collector. The current demand for heat is 18 GWh. The solar collectors can meet a large part of the demand. On hot days, solar collectors can heat up to over 80°C and thus produce HT heat. On less hot days, they heat up to 60°C, which is sufficient to supply the MT heath, while on cold days, the collectors heat water up to 40°C, which can supplement the LT heath.

8.6.2. Deep geothermal

The use of geothermal heat is a sustainable heat source and suitable for large-scale projects. Deep in the earth's crust, at depths of more than 500 meters, there is heat that can be used for heating. The temperature of the subsurface at 2000 meters in Arnhem is about 85°C-80°C, which makes it more than sufficient to supplement the MT-TES, but due to heat lagging it is not sufficient to heat the HT-buildings.

In order to meet the demand for HT-heat, an even deeper search for heat is required. For deep geothermal, from depths below 4000 meters, the temperatures are around 120°C. At temperatures higher than 100°C, the heat can be used to produce electricity by means of turbines. Due to a lack of knowledge of the subsurface and the high cost of drilling, deep geothermal energy is currently not used as a heat source in the Netherlands. Moreover, there are no regulations for this heat source yet. City-zen, however, notes the developments in the field of deep geothermal energy will ensure that this is the source for HT-heat in the future.

8.6.3. Biomass

Another renewable heat source is biomass. Biomass is based on incineration and consists of two principles. One is to create a biofuel by fermenting wet biomass, such as kitchen waste, garden waste and waste from industry or agriculture. Another way is to burn the dry biomass itself, such as burning pruning and waste wood.

Even though biomass is a renewable source, as the source of this principle is renewable, it is not by definition sustainable. The production of biomass can emit more CO2 than burning fossil fuels. Greenery can also be displaced, and the production of biomass can compete with food production (environment centrally, n.d.). Biomass is considered sustainable if the entire chain has no harmful environmental effects, i.e. sufficient greenery must be replanted, natural resources must be used as much as possible, and the conversion of biomass into usable energy must have the highest possible yield (Environment central, n.d.).

Domestic production of organic waste amounts 57.8 kg per person, which corresponds to a total production of 34.9 tonnes of organic waste. In addition, 50 kg of organic waste per person is produced within offices, which is equivalent to 461 tonnes of organic waste. For the other building functions, it is assumed that a total of 95 tonnes of organic waste is produced. All in all, 600 tonnes of GFT waste is being produced. According to RVO, approximately 100 Nm3 of biogas is produced per ton of GFT. This amounts to a total production of 60,000 Nm³ biogas. This biogas has a total heat potential of 0.6 GWh, which amounts to 1.42% of the total heat demand.

8.7. Output - 2025

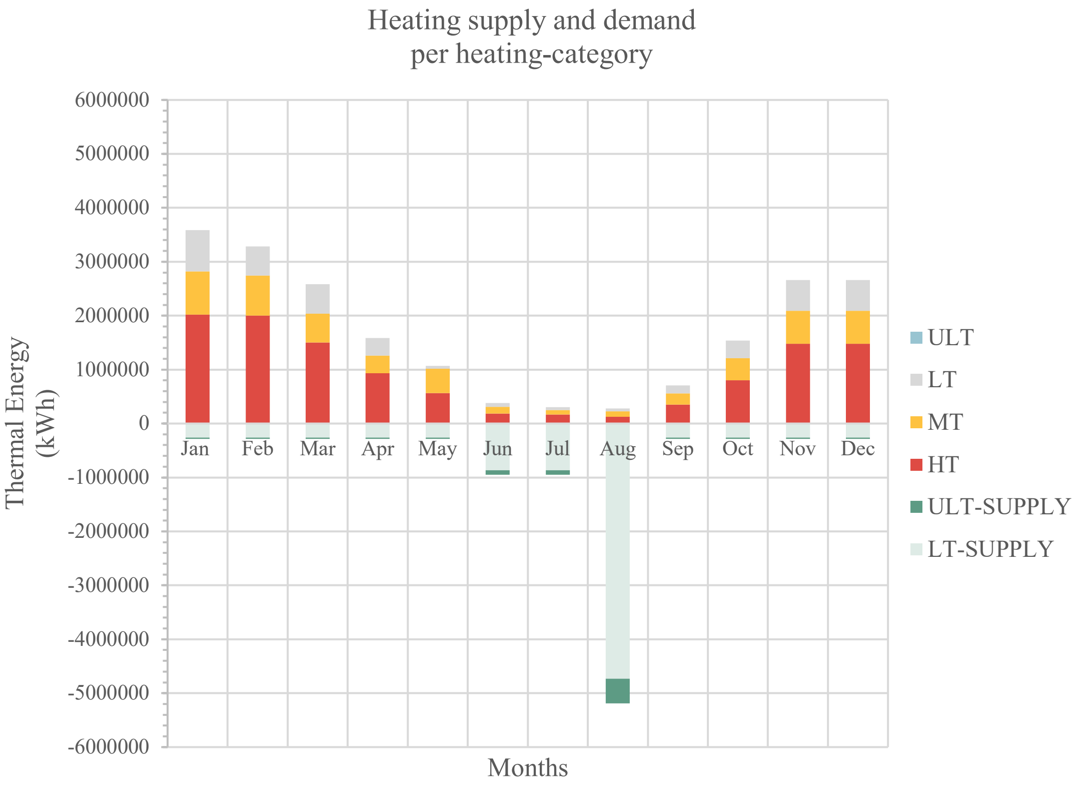


Figure 1: Heating demand and supply per heat category (2025). Own image, 2019

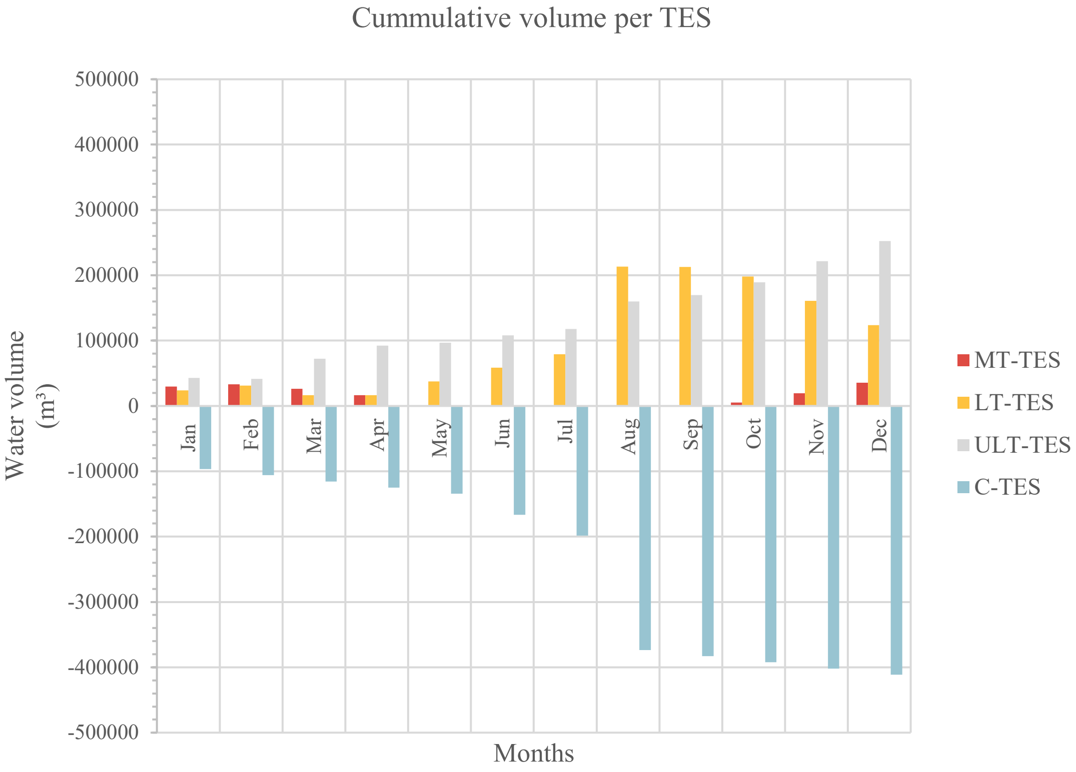


Figure 2: Cumulative water volume per TES (2025). Own image, 2019

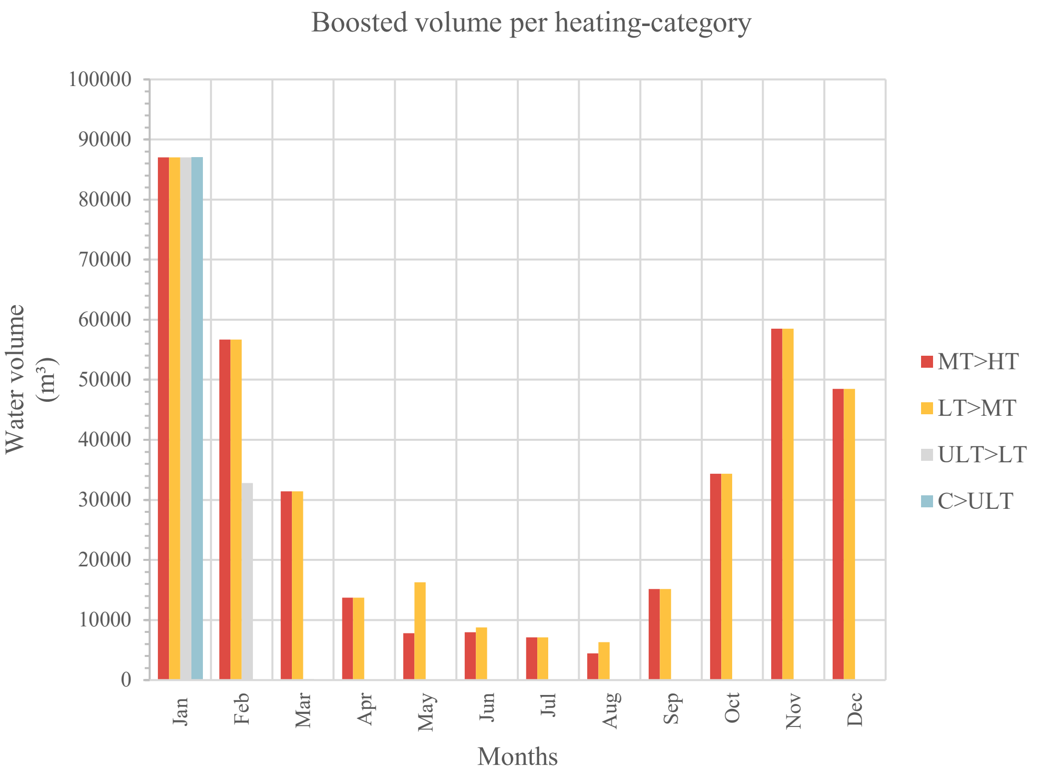


Figure 3: Volume water boosted in temperature (2025). Own image, 2019

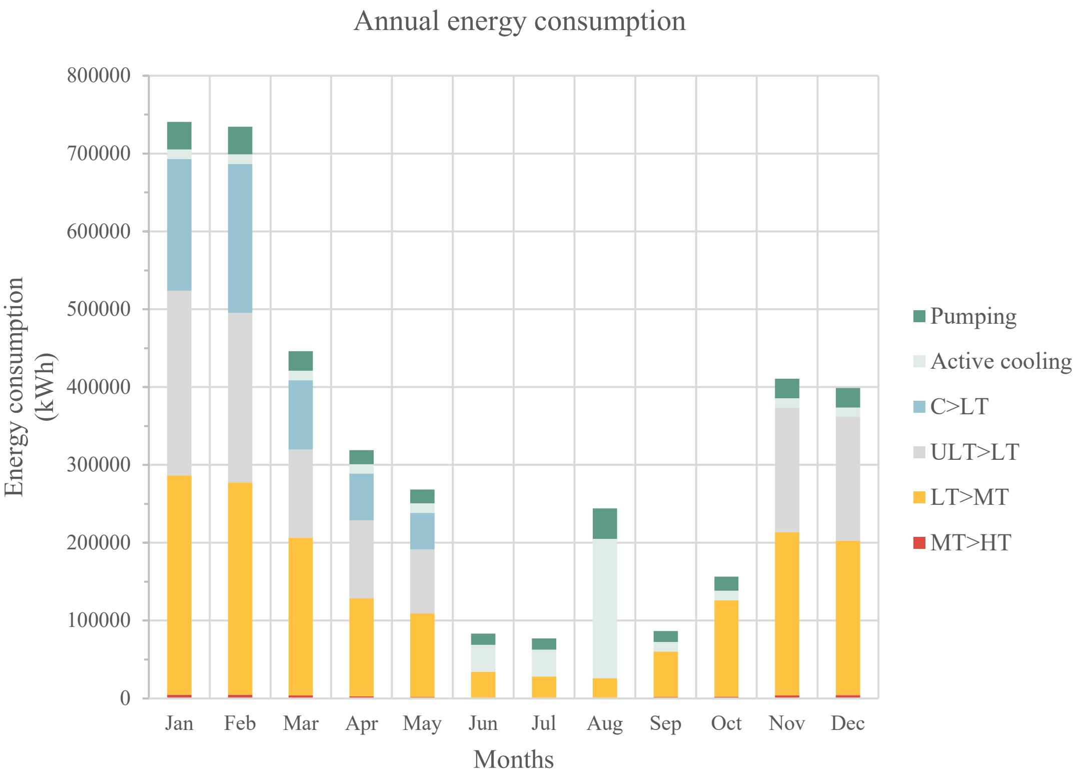


Figure 4: Annual energy consumption (2025). Own image, 2019

8.8. Output - 2030

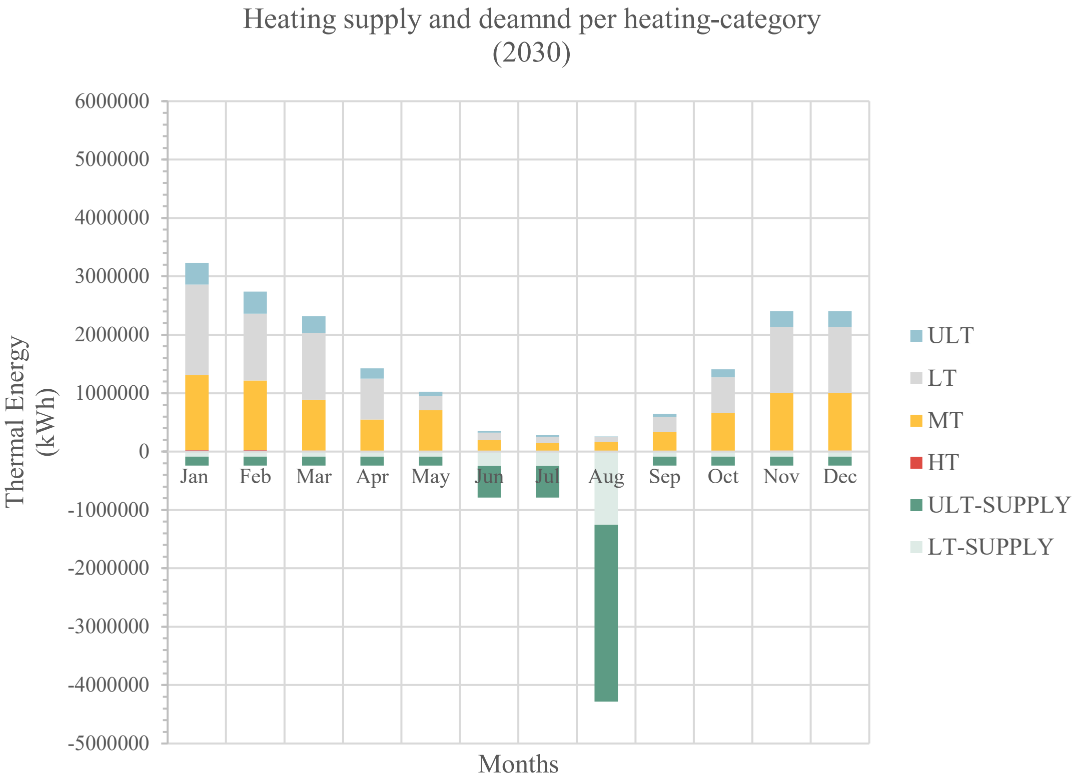


Figure 1: Heating demand and supply per heat category (2030). Own image, 2019

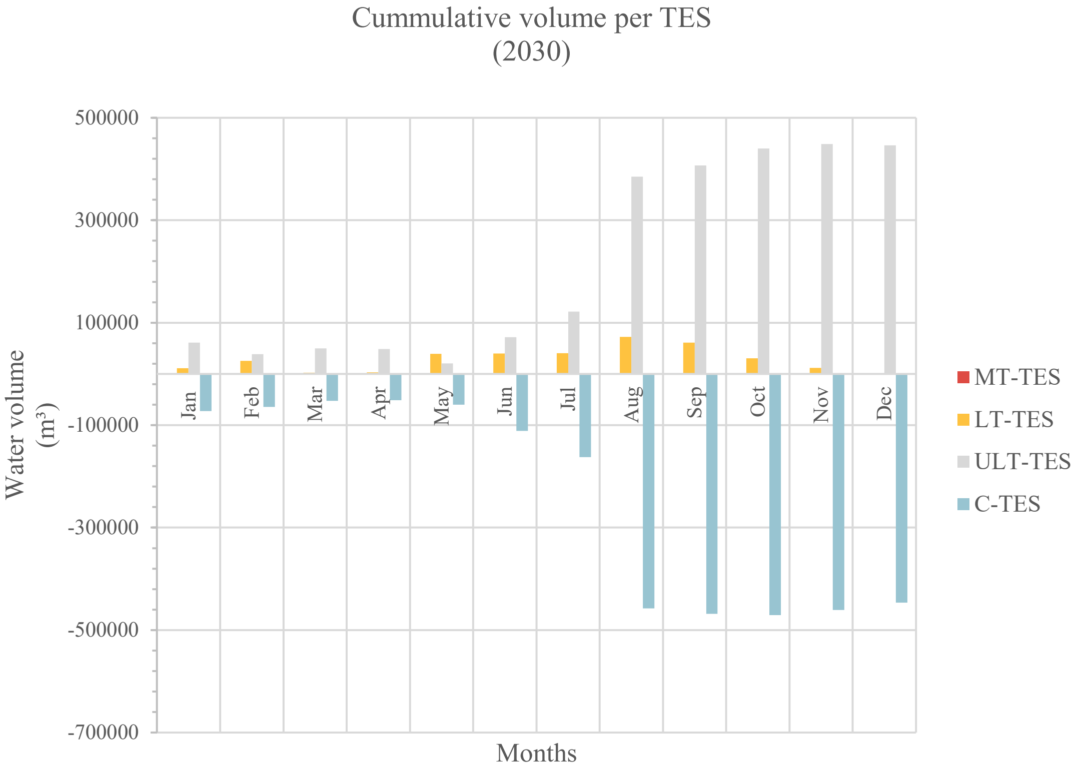


Figure 2: Cumulative water volume per TES (2030). Own image, 2019

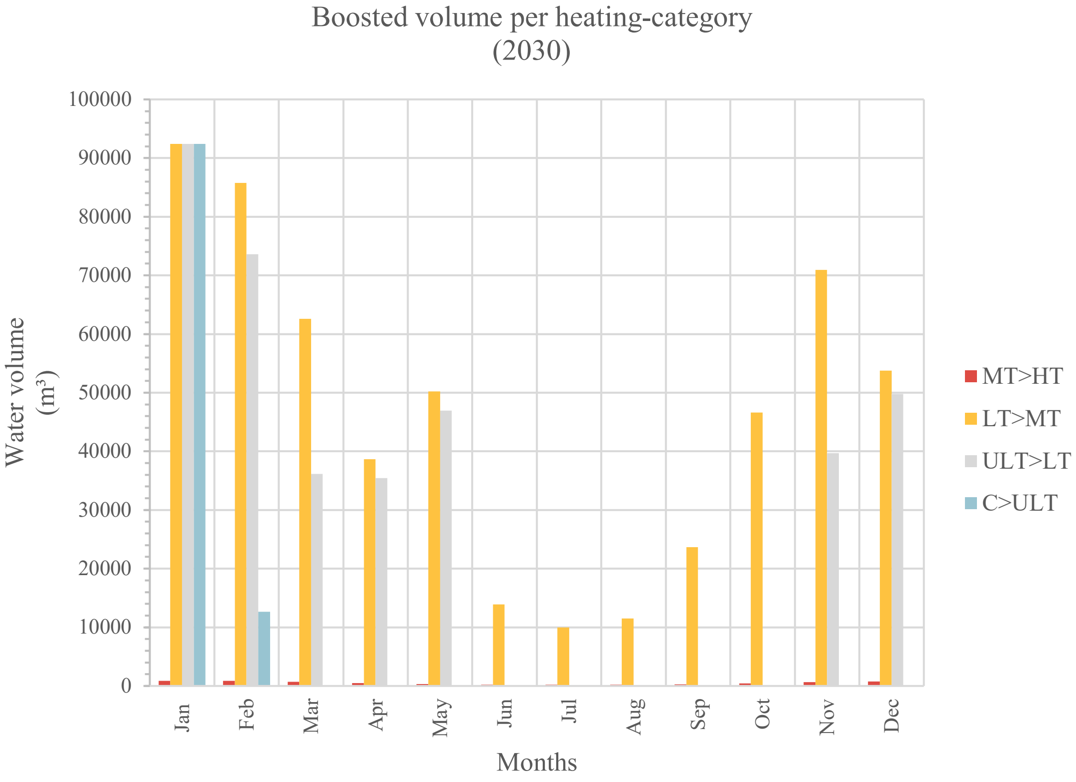


Figure 3: Volume water boosted in temperature (2030). Own image, 2019

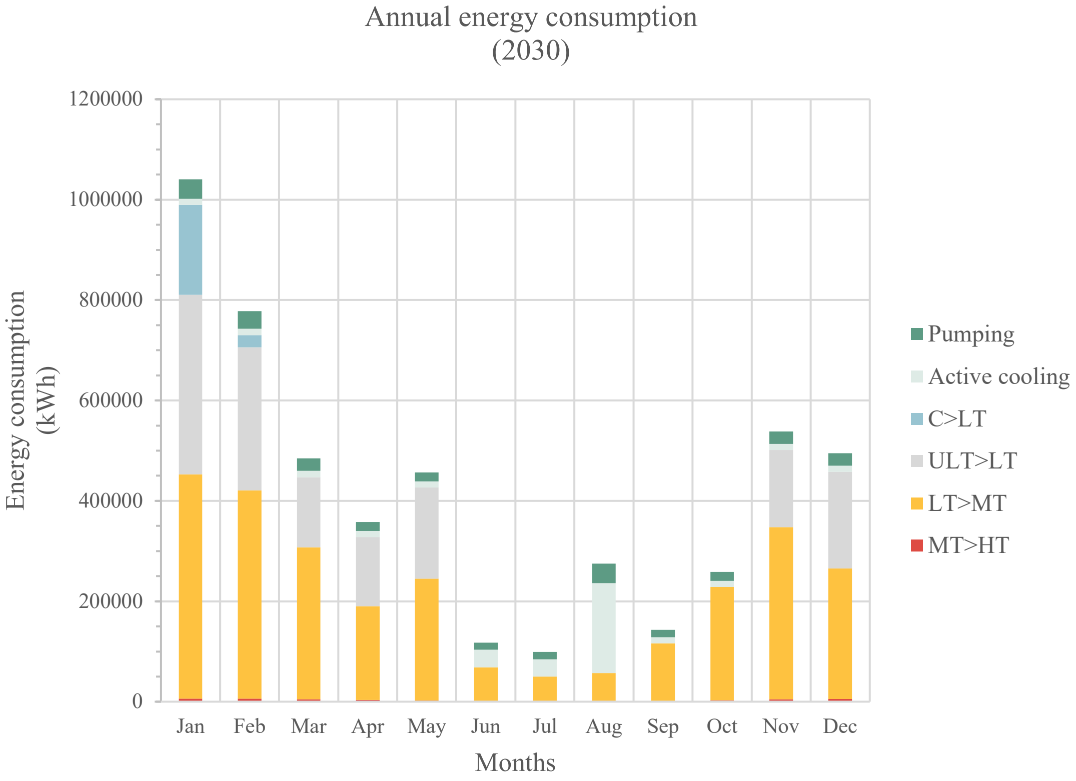


Figure 4: Annual energy consumption (2030). Own image, 2019

8.9. Output - 2040

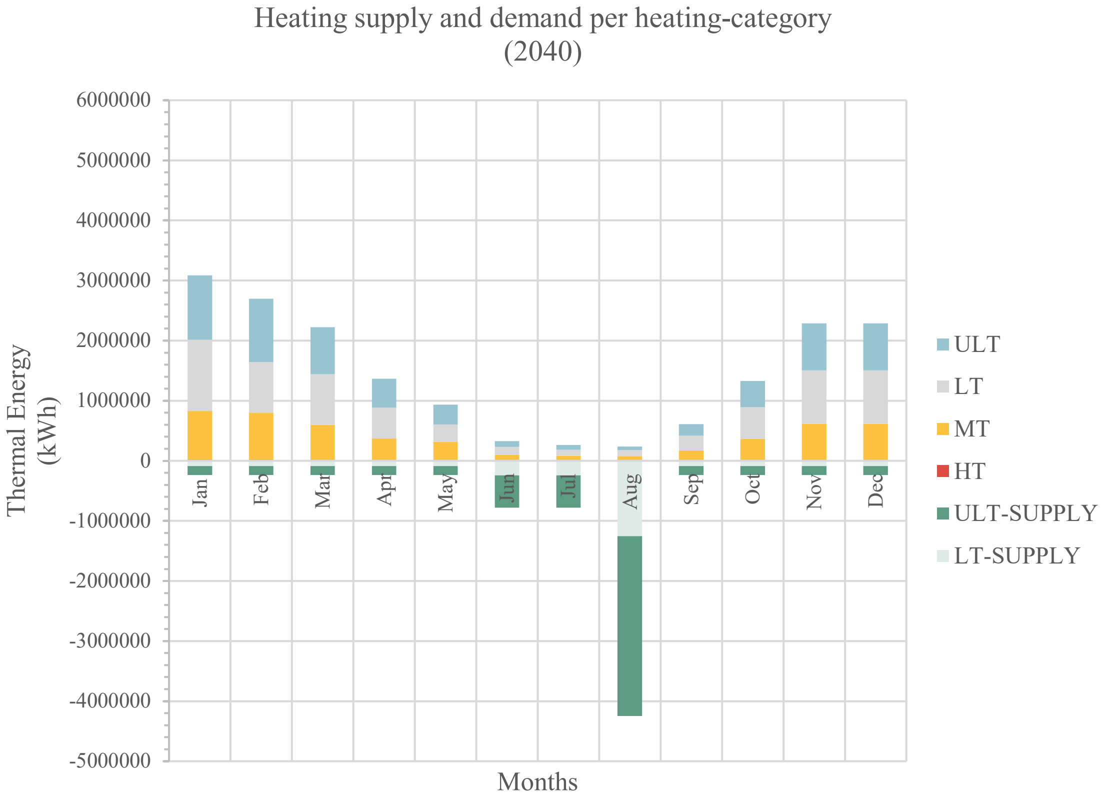


Figure 1: Heating demand and supply per heat category (2040). Own image, 2019

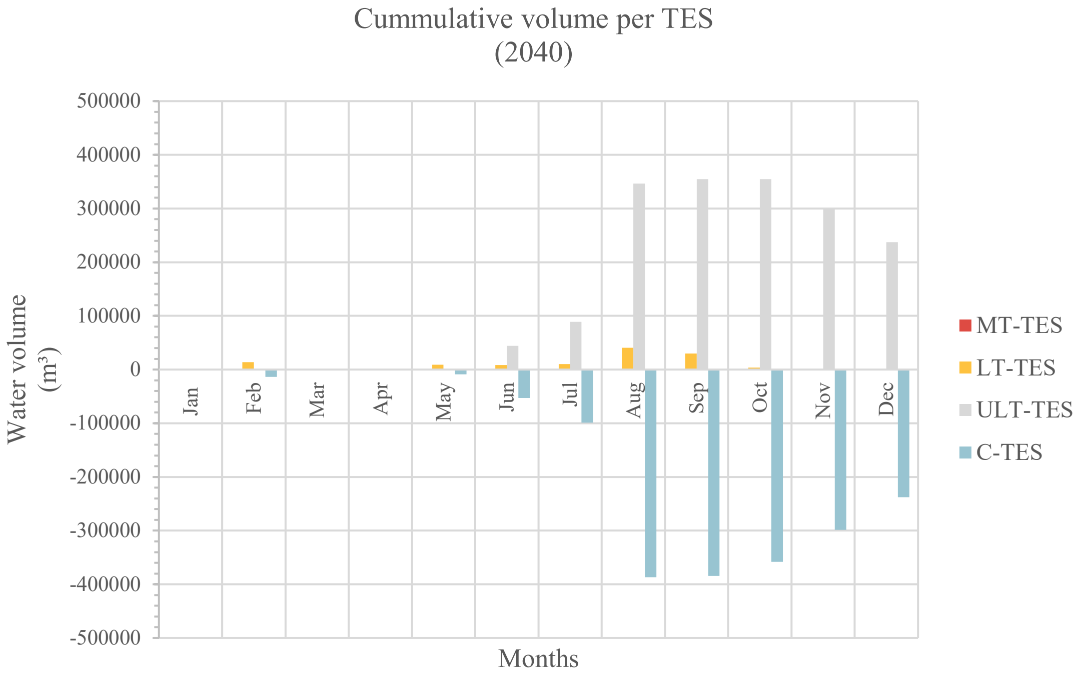


Figure 2: Cumulative water volume per TES (2040). Own image, 2019

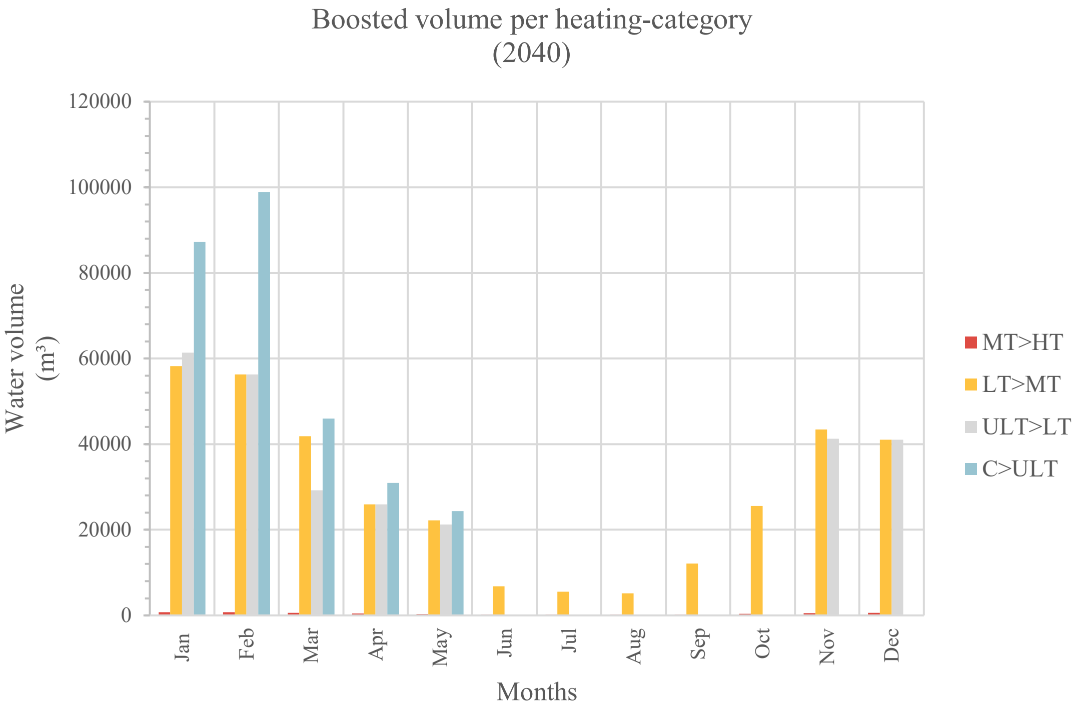


Figure 3: Volume water boosted in temperature (2040). Own image, 2019

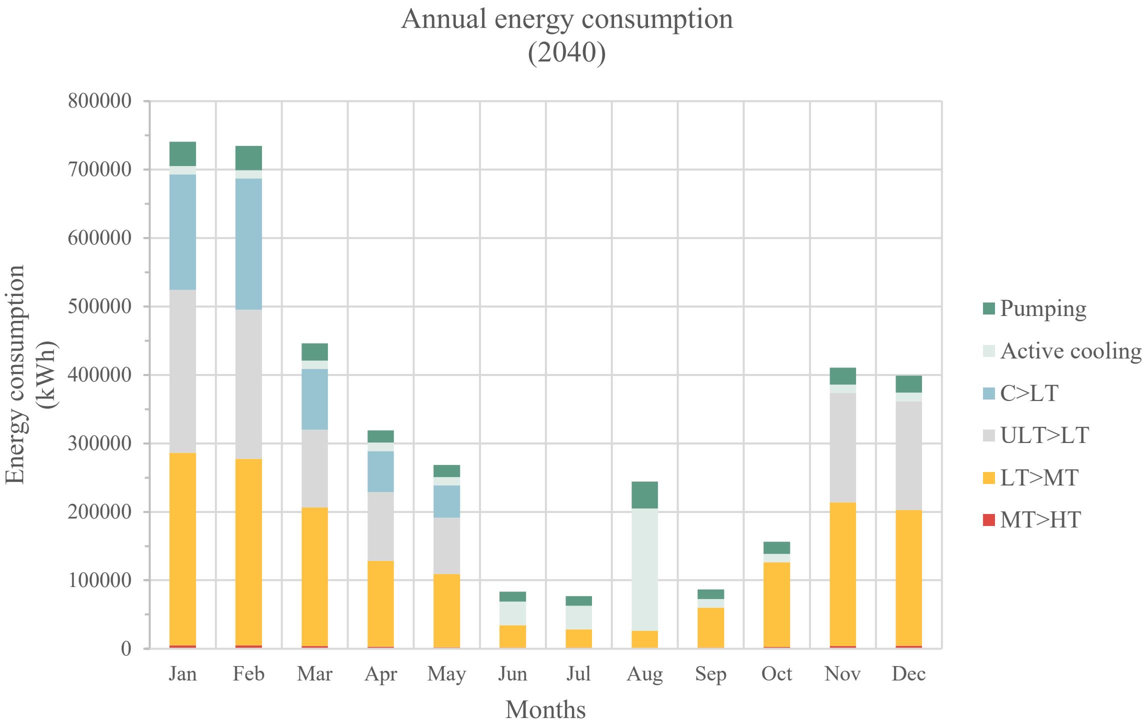


Figure 4: Annual energy consumption (2040). Own image, 2019